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Technical Report

NEW AND MODIFIED ANCHORS FOR MOORINGS

621 000

U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

NEW AND MODIFIED ANCHORS FOR MOORINGS

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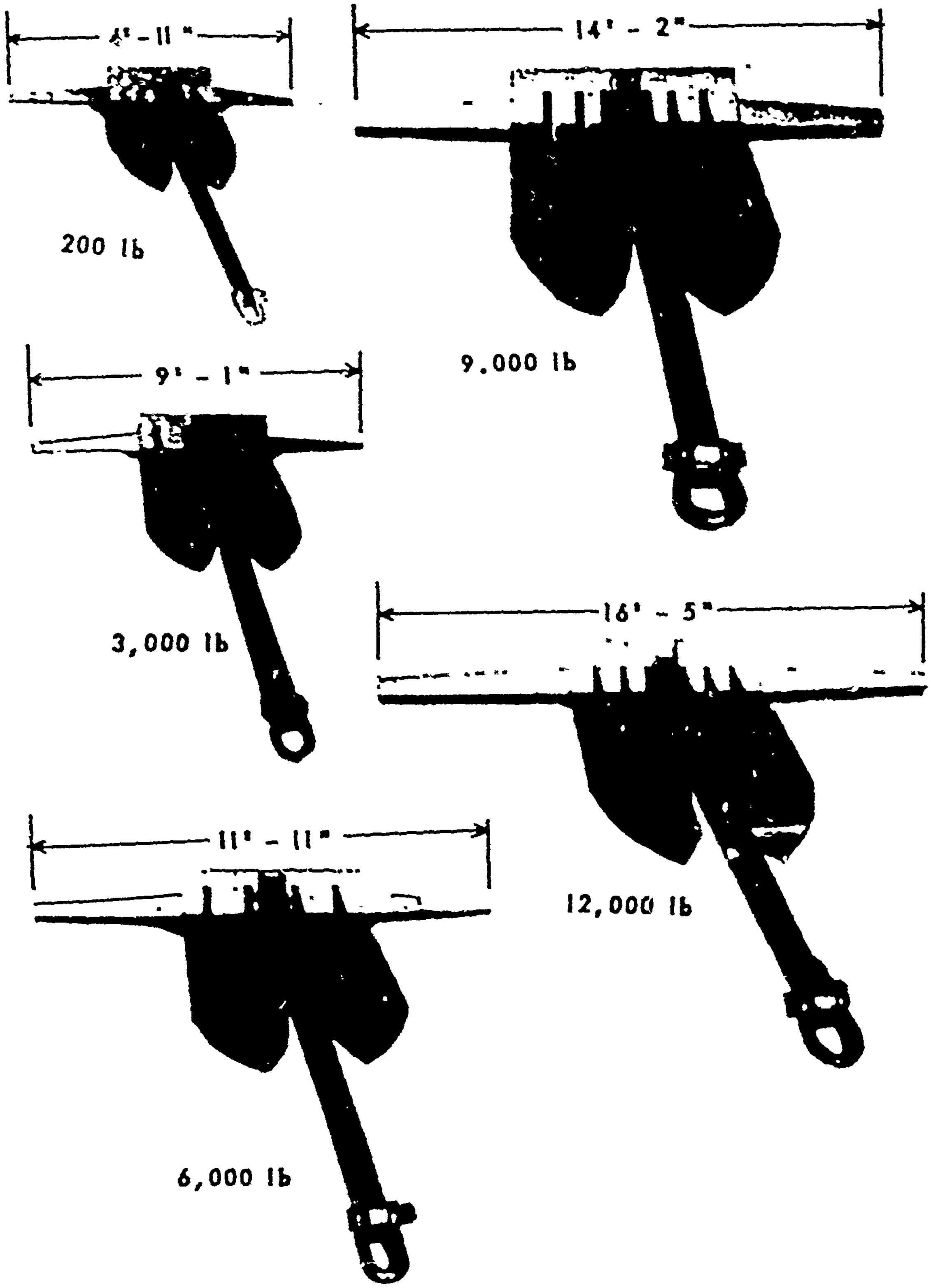
Type B
Final Report

14 March 1960

by

R. C. Towne
J. V. Stalcup

U. S. NAVAL CIVIL ENGINEERING
LABORATORY
Port Hueneme, California



"Family" of BuDocks STATO mooring anchors.

FOREWARD

Anchors and particularly mooring anchors, have been developed intermittently for many years. Much of the past work in this or related fields has been confined to model studies because the equipment required for full-scale tests is large and expensive and because there are many variables such as anchor shapes, sizes, stabilizers, soil types, etc. The Bureau of Yards and Docks, which is responsible for developing permanent-type moorings, initiated a comprehensive program in November 1947 to improve the efficiency of the Navy Stockless anchors and to develop a more suitable design criteria for mooring anchors. This program was undertaken by the U. S. Naval Civil Engineering Laboratory, Port Hueneme, California, with full-scale anchors and with test equipment which could simulate ship mooring in sand and mud (clay) type bottoms. Tests could not be conducted in rock or coral bottoms because of the unavailability of suitable test sites.

Approximately 3,000 test pulls were conducted during the period from November 1947 to December 1958 on anchors ranging in weight from 75 pounds to 30,000 pounds.

The tests covered by this report (1955-1958) were made to develop a "family" of new mooring anchors, which is light weight, has optimum efficiency in sand and mud bottoms, and develops from 6,000 lb to 210,000 lb holding power. These tests continued the anchor development studies conducted during the period from 1947-1955.

OBJECT OF PROJECT

To develop mooring anchors with improved stability and greater holding powers than existing anchors obtain in sand, mud, and clay bottoms.

OBJECT OF TASK

To develop a "family" of new mooring anchors having characteristics such as light weight, stability, fabrication from mild steel, low cost, and higher holding power in sand and mud bottoms than anchors presently used in Bureau of Yards and Docks moorings.

OBJECT OF REPORT

This final report describes the design and development of a "family" of mooring anchors which is lightweight, performs efficiently in sand or mud bottoms and provides a range of holding powers o: 6,000 lb to 210,000 lb.

ABSTRACT

Existing fleet mooring anchors have, in many instances, behaved erratically under load due to rotational instability and insufficient holding power in varying types of bottoms. In November 1947, the Bureau of Yards and Docks directed the U. S. Naval Civil Engineering Laboratory to test present standard anchors to: 1) determine their behavior and holding power in sand, mud and clay, 2) compile factual data for modifications of existing anchor types and 3) develop design criteria for new, more efficient mooring anchors. Upon completion of tests on the current type anchors in May 1955, the Laboratory developed and fabricated a "family" (200 lb, 3,000 lb, 6,000 lb, 9,000 lb, 12,000 lb) of new mooring anchors which is capable of holding powers ranging from 6,000 lb to 210,000 lb in a sand bottom, and can operate more efficiently in mud than present type stockless or commercial anchors with stocks.

From the results of the investigation of the new mooring anchor, it was concluded that this anchor will satisfy the physical and operational requirements specified by BuDocks.

It is recommended that the new mooring anchors be used in permanent type moorings on various types of soil bottoms in an in-service evaluation test to provide operational information on performance characteristics.

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INTRODUCTION

The Bureau of Yards and Docks is responsible for the construction of Fleet mooring facilities. Anchors and ground tackle are utilized in the installation of these moorings for all types of vessels, floating drydocks, cranes and similar types of craft. The Navy stockless type anchors are used most often for these moorings but they have poor rotational stability and a small holding-power-to anchor-weight ratio. They are unsuitable for moorings placed in locations with limited drag space where the mooring cannot be permitted to drag because of proximity to obstacles. Because of its interest in improving the holding power characteristics of the stockless anchor and in developing an improved mooring anchor BuDocks conducted model studies and allied research to improve the stockless type anchor. Following this, the U. S. Naval Civil Engineering Laboratory at Port Hueneme, California conducted full scale studies and investigations [1,2,3] from 1947 to 1955.

From 1955 to 1958 and at the direction of BuDocks[4], the tests described in the body of this report were conducted to develop a "family" of new mooring anchors which is light weight, stable, fabricated from mild steel, low cost, and has optimum efficiency in sand and mud bottoms. In addition, these advantages were to be achieved with a minimum number of anchor sizes which would provide holding powers of 6,000 lb to 210,000 lb in sand bottoms.

Others have developed efficient anchor fluke shapes and dimensional relationships between anchor parts so only minor improvements along these lines were accomplished during the design of the new mooring anchor. While extensive study and efforts were made to determine the correct dimensions for the new anchors, probably the most important improvements were the concept of field adjustment of the fluke angle from 34 degrees for sand operation to 50 degrees for mud operation; and the addition of palm extensions which cause the anchors to bury themselves in mud bottoms.

ANCHOR DESIGN

The holding power of the Navy stockless-type anchor is based on the anchor fluke area, but for convenience holding power is expressed in terms of anchor weight and is approximately 6 times the anchor weight in air for stockless-type anchors operating in a sand bottom. (BuDocks Manual, Mooring Guide Volume 1, NAVDOCKS TP-PW-2, March 1954). The real function of anchor weight is to reinforce the anchor for operation and to help it penetrate the initial resistance of the sea bottom.

The results of the tests conducted by NCEL from 1947 to 1955 to improve the Navy stockless-type anchors were used to establish design criteria for an improved mooring anchor. These design criteria are:

(1) Light weight.

(2) Two flukes which can rotate a maximum of 50 degrees either side of the shank. (This type of construction is advantageous in that there is no right or wrong side and the anchor may be set without regard to a right-side-up position.)

(3) The fluke angle be adjustable by field alteration from a 50-degree angle for mud to a 34-degree angle for sand bottoms.

(4) The crown be kept to a minimum size to reduce bottom resistance.

(5) Stabilizers be used to ensure proper orientation of the anchor and thereby a more uniform holding power.

(6) Sufficient tripping palm area be provided to assure positive fluke tripping in mud bottoms. (It had been determined that one primary cause of low holding power in mud was the inability of the anchor flukes to trip and begin setting into the bottom. "The anchor flukes are forced upward due to the vertical reaction of the mud against the bottom area of the flukes as they settle through the soft material. Therefore a tripping plate with sufficient area to overcome this mud reaction against the flukes must be provided or the anchor will skid along with the flukes in a raised position.[3]")

In addition to the above design specifications BuDocks requested that:

(1) A "family" of anchors be developed with holding powers from 6,000 lb to 210,000 lb.

(2) The number of anchors comprising the "family" be kept to the most practical minimum.

(3) The anchors be welded using plates of mild steel for construction.

(4) The holding power of anchor be described as that holding power resulting after anchor has dragged a distance of 50 ft. In accordance with the established criteria, a holding power to anchor weight ratio of 20 to 1 was selected as being the best ratio to provide a minimum number of anchors which would produce the required holding powers and allow the other design requirements to be met. Corresponding anchor weights to holding powers were established as shown below.

Anchor Weight (Pounds)	Holding Power (Pounds)
200	6,000
3,000	30,000 to 60,000
6,000	90,000 to 120,000
9,000	150,000 to 180,000
12,000	210,000

The new anchors, named BuDocks STATO[5] mooring anchors, (see Frontispiece) were designed with two movable flukes. The requirement for using mild steel necessitated the addition of stiffeners along the length of the flukes, although model studies[6] have indicated that higher holding powers can be obtained with anchors having smooth surfaced flukes rather than flukes with stiffeners. The fluke aspect ratio (total area of 2 flukes to fluke length squared) was established at approximately 0.50 to provide the required holding power in the selected sand and mud test areas. The length and width dimensions of the flukes for the STATO anchors are listed in Table I.

The optimum fluke angle as determined experimentally is 34 degrees for sand[1] (Figure 1) and 50 degrees for mud[3] (Figure 2). Fluke angle, as used in this report, is the angle subtended by the center line of the shank and the flukes when the flukes are rotated to the extreme open position. To comply with BuDocks request for field adjustment of the fluke angle, it was decided that the anchors would be fabricated with a 50 degree fluke angle and that a wedge insert, held in place by bolts, would be used to reduce the angle to 34 degrees, (Figures 3 and 4).

Table 1. BuDocks STATO Anchor Dimensions

Anchor weight lb	Fluke area* sq in.	Fluke length in.	Fluke width in.	Shank length in.	Stabilizer length in.	Mud-palm extensions sq in.
200	432	26	10	42	18	120
3000	2246	69	18	129	34	574
6000	3540	82	24	144	44	852
9000	4580	96	27	160	54	961
12000	5674	108	30	186	64	1190

* Area of both flukes.

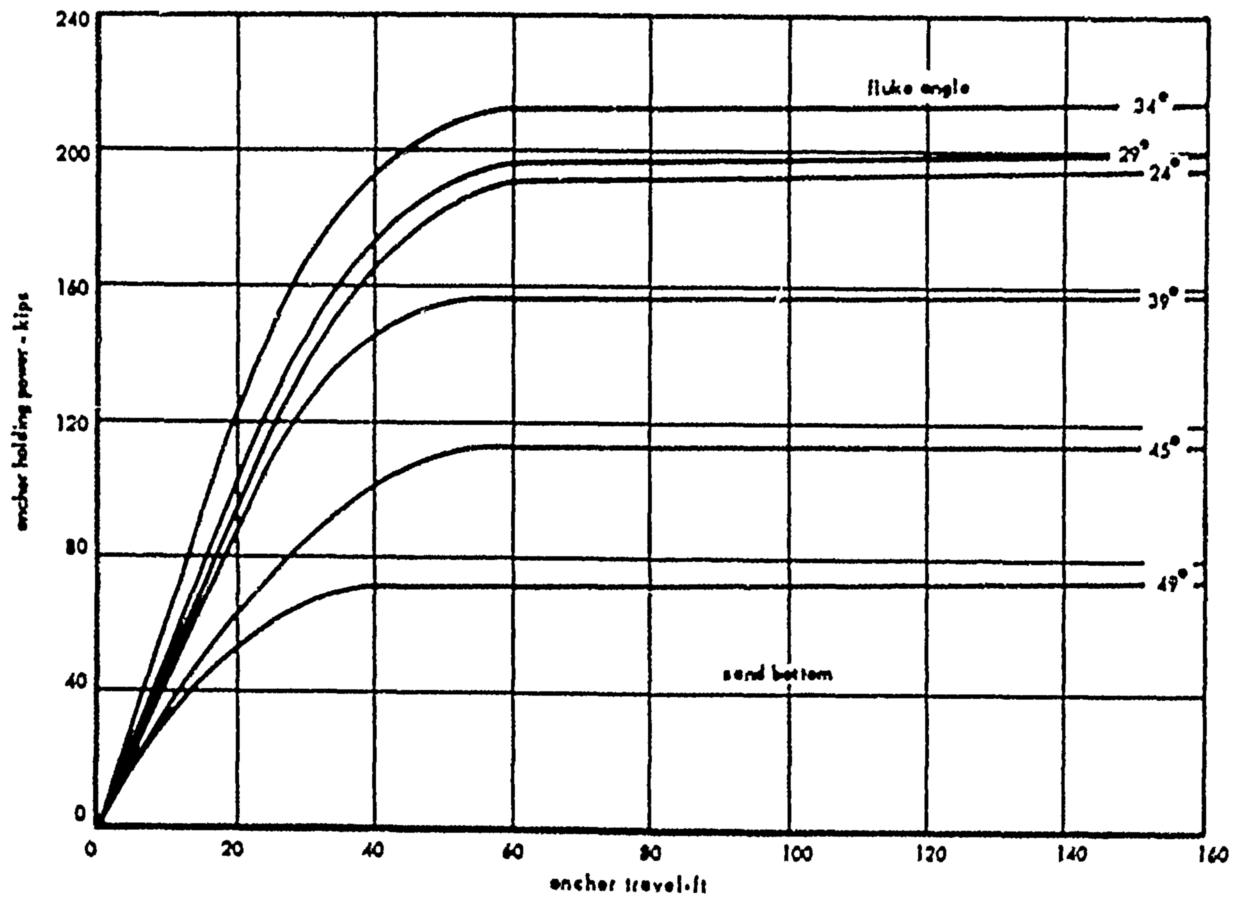


Figure 1. Graph of fluke angle test in sand bottom.

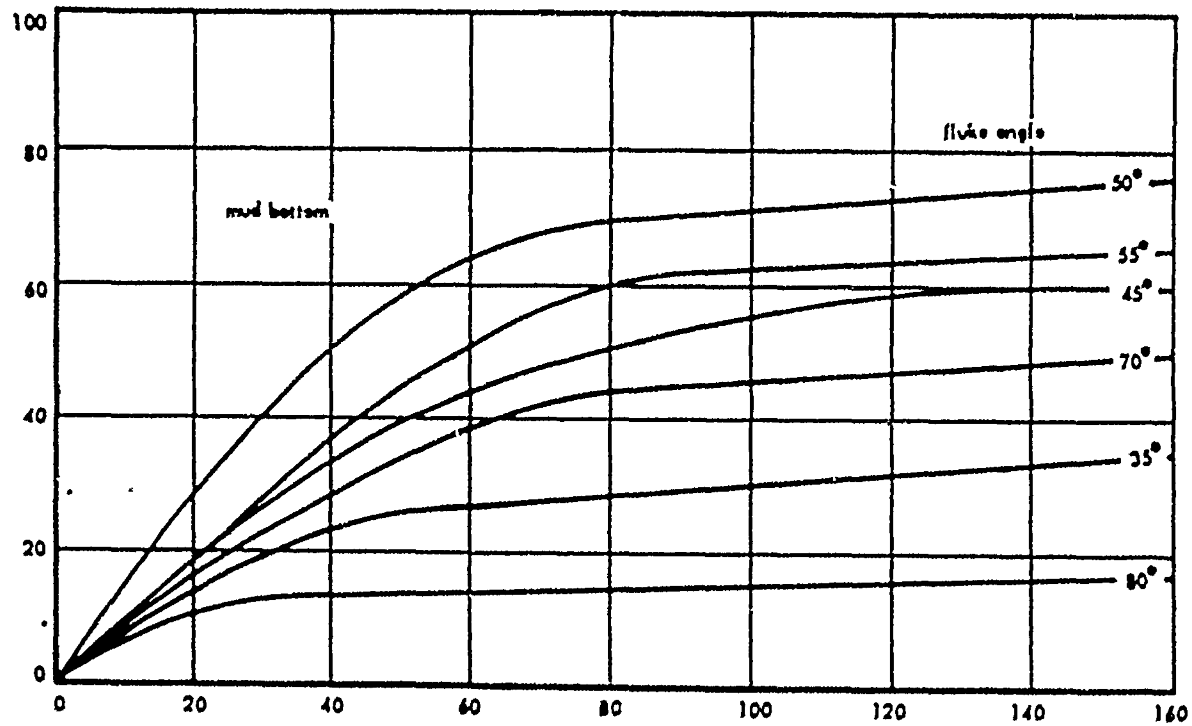


Figure 2. Graph of fluke angle test in mud bottom.

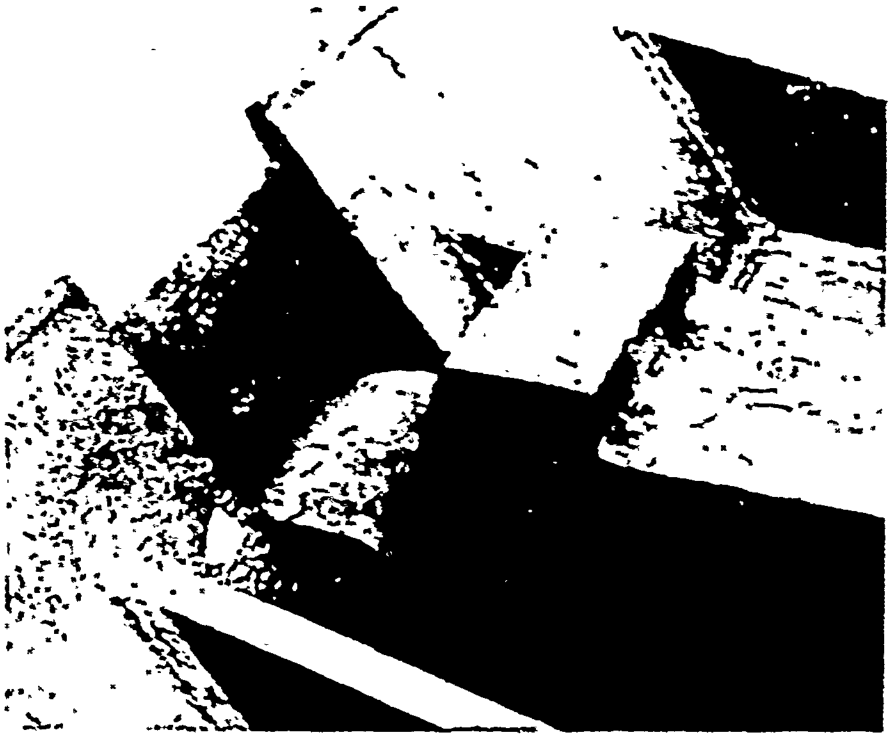


Figure 3. BuDocks STATO mooring anchor without wedge insert.

Figure 4. BuDocks STATO mooring anchor with wedge insert bolted in place.

During the previous sand tests it became apparent that the ratio of the fluke length to shank length was very important to setting and burying anchors and that anchors which would be expected to bury themselves to considerable depths would be very sensitive to variations of this fluke/shank ratio. This is especially true in sand bottoms which have greater resistance to anchor penetration than mud. A fluke/shank length ratio of 0.60 was determined by test[1] to be the best ratio for these anchors. The flukes were sharpened at the tips and the shank was beveled on the upper and lower edges to facilitate burial. For the same reason, the design of the anchor crown required that its size be held to the minimum required for proper strength. It was necessary, moreover, to provide adequate tripping action; the tripping palms were set at angles of 130 degrees from the fluke. The ratio of the crown thickness/fluke length was set at 0.29, but this changed to 0.54 when palm extensions were used.

The size and shape of the stabilizers were determined from the results and observations of previous tests[1,2,3]. The shape and angle of the stabilizers had been observed to affect holding power when the angle of the Stabilizer plates were varied as little as 5 degrees. The length of the stabilizers for each weight anchor is shown in Table I and is detailed on Yards and Docks drawings 813506 through 813521, Appendix "A". The five anchors as constructed are shown in Figures 5 through 9.

The problem of proof loading a mooring anchor or any anchor has been investigated by others and opinions vary on the method and amount of applied load. Mr. K. P. Farrel in his report[7] states the problem clearly. For the mooring anchors described in this report, the proof load was based on the designated anchor holding power in a sand bottom at 50 ft drag: Pl = 1-1/2 HP (Pl = proof load; HP = holding power at 50 ft.) This is equivalent to a load of approximately 30 times the anchor weight. The proof load was applied to the flukes at a point L/3 from the fluke tips (L = length of fluke.) No spacer was used between the shank and flukes during the test. Proof loads for the STATO mooring anchors are shown in Table II.

ANCHOR TESTING APPARATUS

The sand and mud bottom test apparatus consisted of two 5 by 12 (35 ft by 72 ft) Navy Lighter pontoon barges for carrying the test equipment, a 5 by 14 (35 ft by 83 ft) Navy Lighter pontoon warping tug for dropping and retrieving the anchors; a 400,000-lb capacity electric dynamometer to measure the holding powers of the anchors; and a Model BU-140 Skagit winch (Figure 10) to drag the anchors. The winch was spooled with 2,500 ft of 1-3/8 in. diameter wire

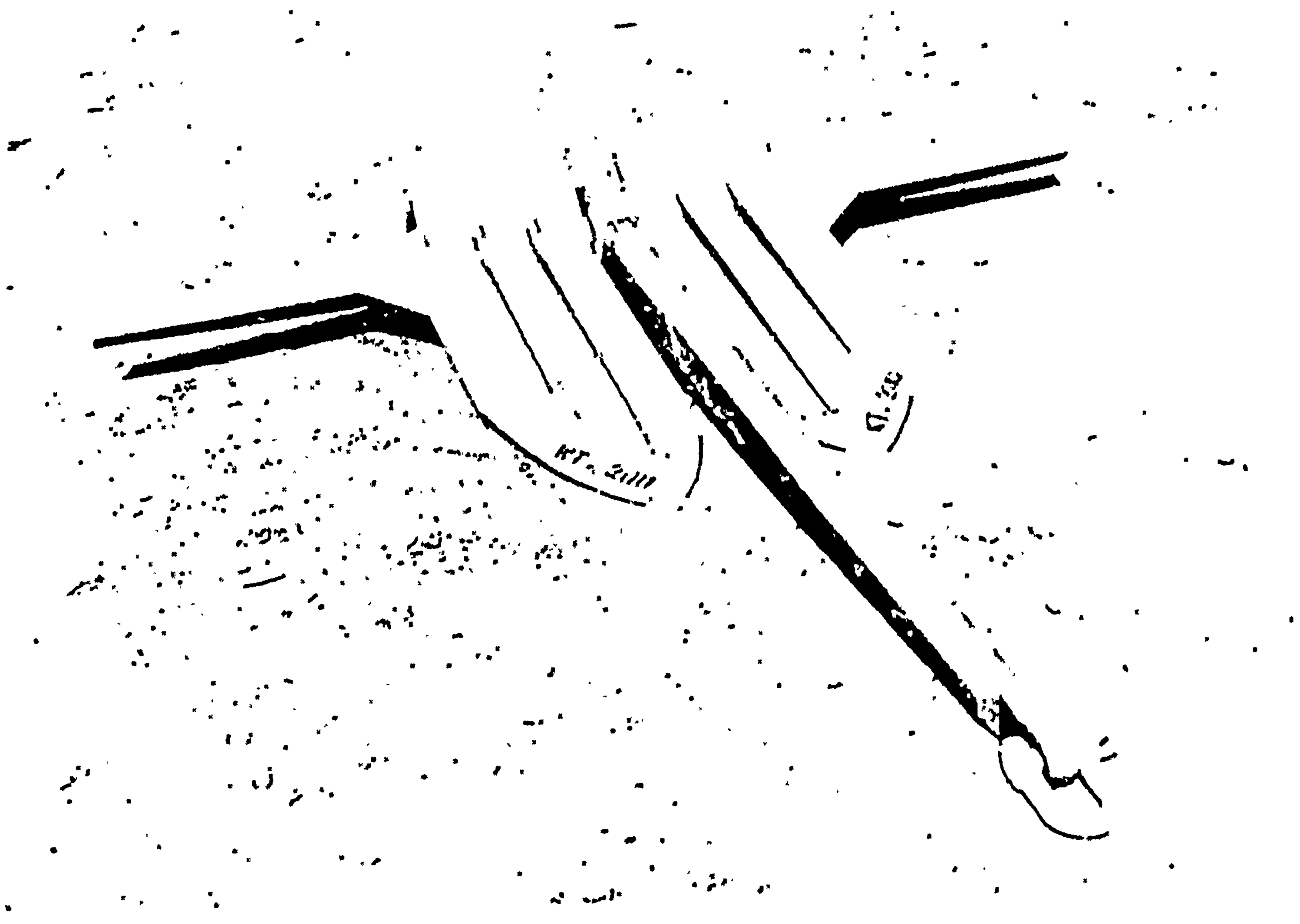


Figure 5. 200-lb Bullocks STATO mooring anchor.

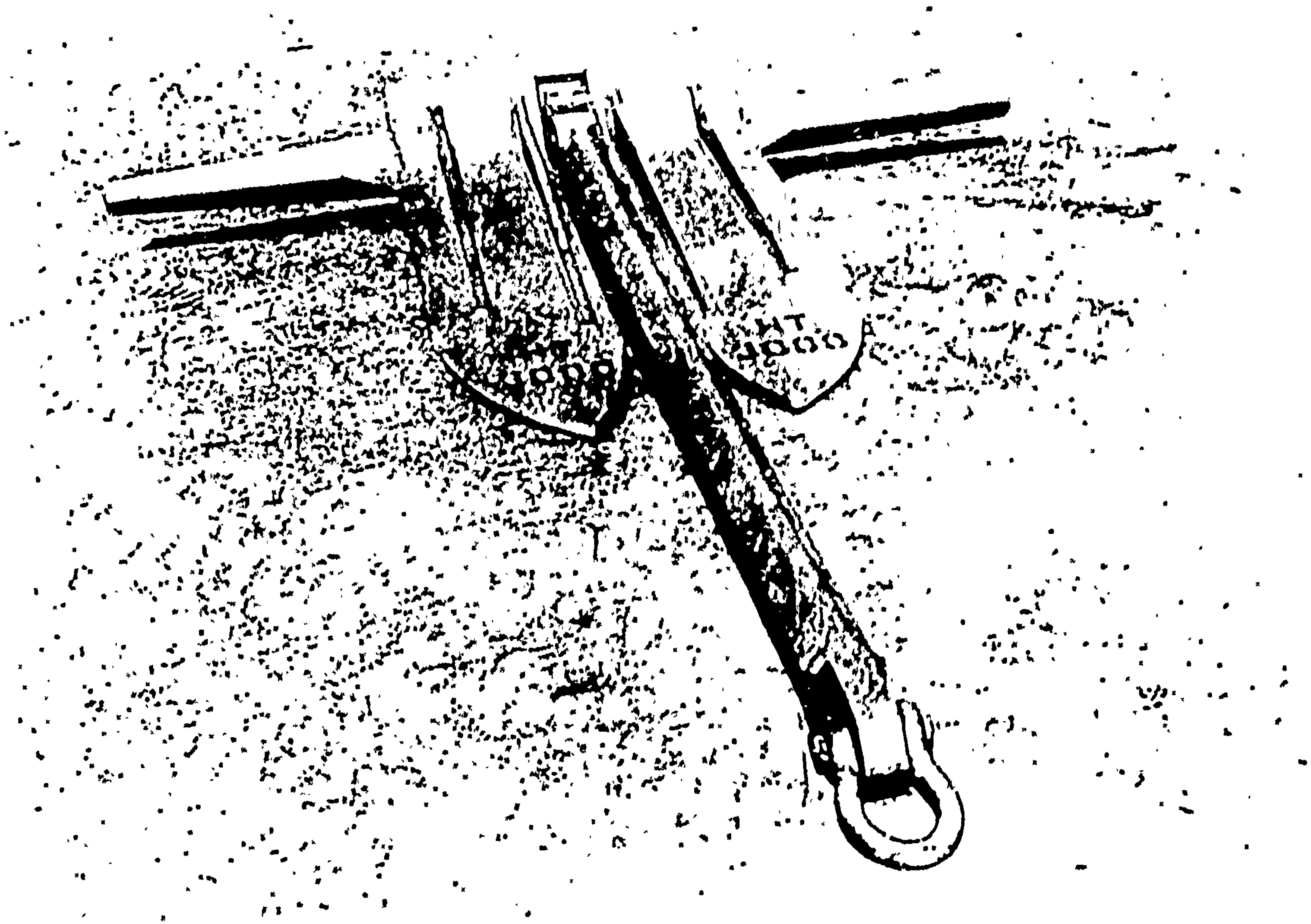


Figure 6. 3000-lb BuDocks STATO mooring anchor.

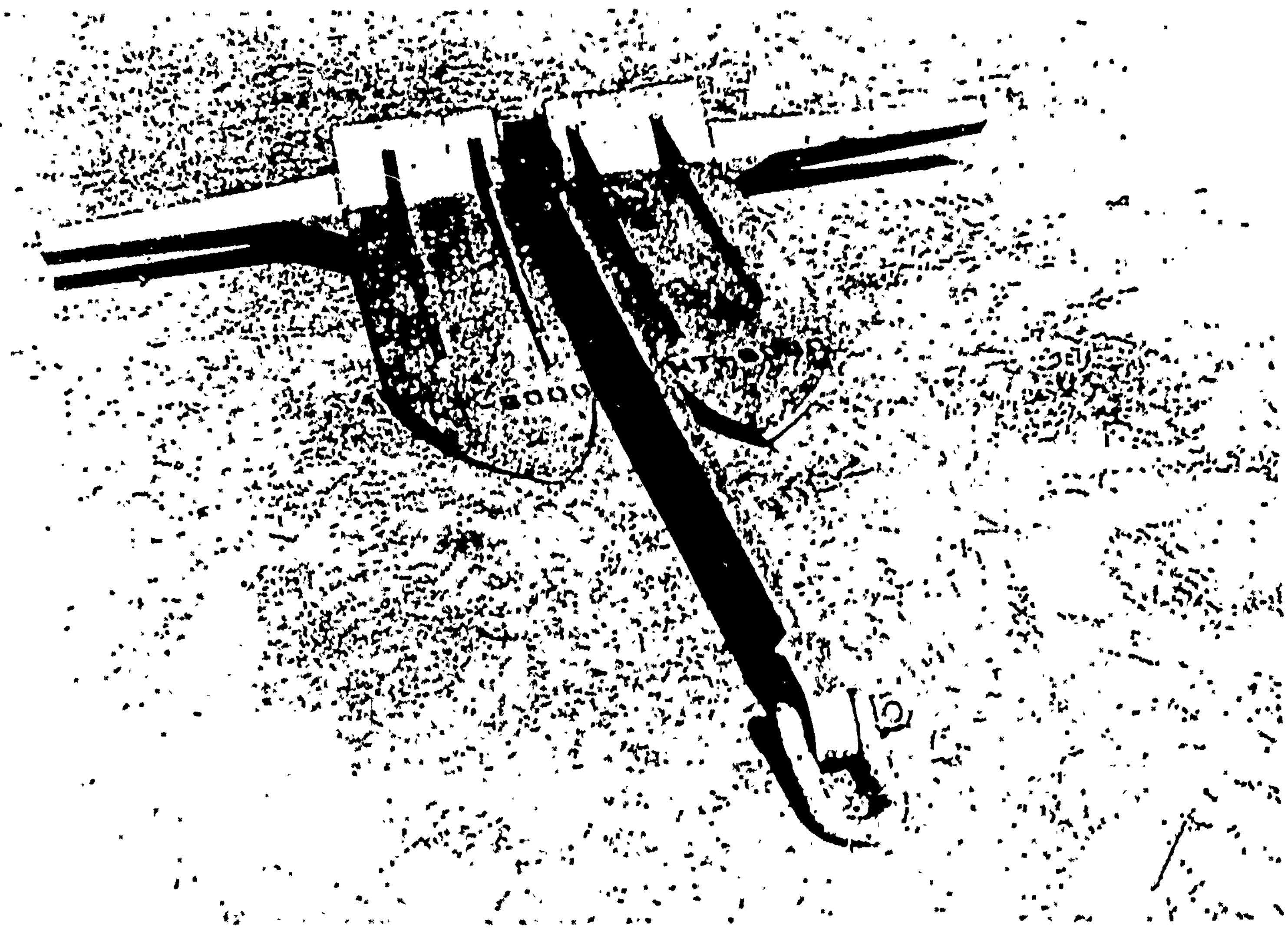


Figure 7. 6000-lb BuDocks STATO mooring anchor.

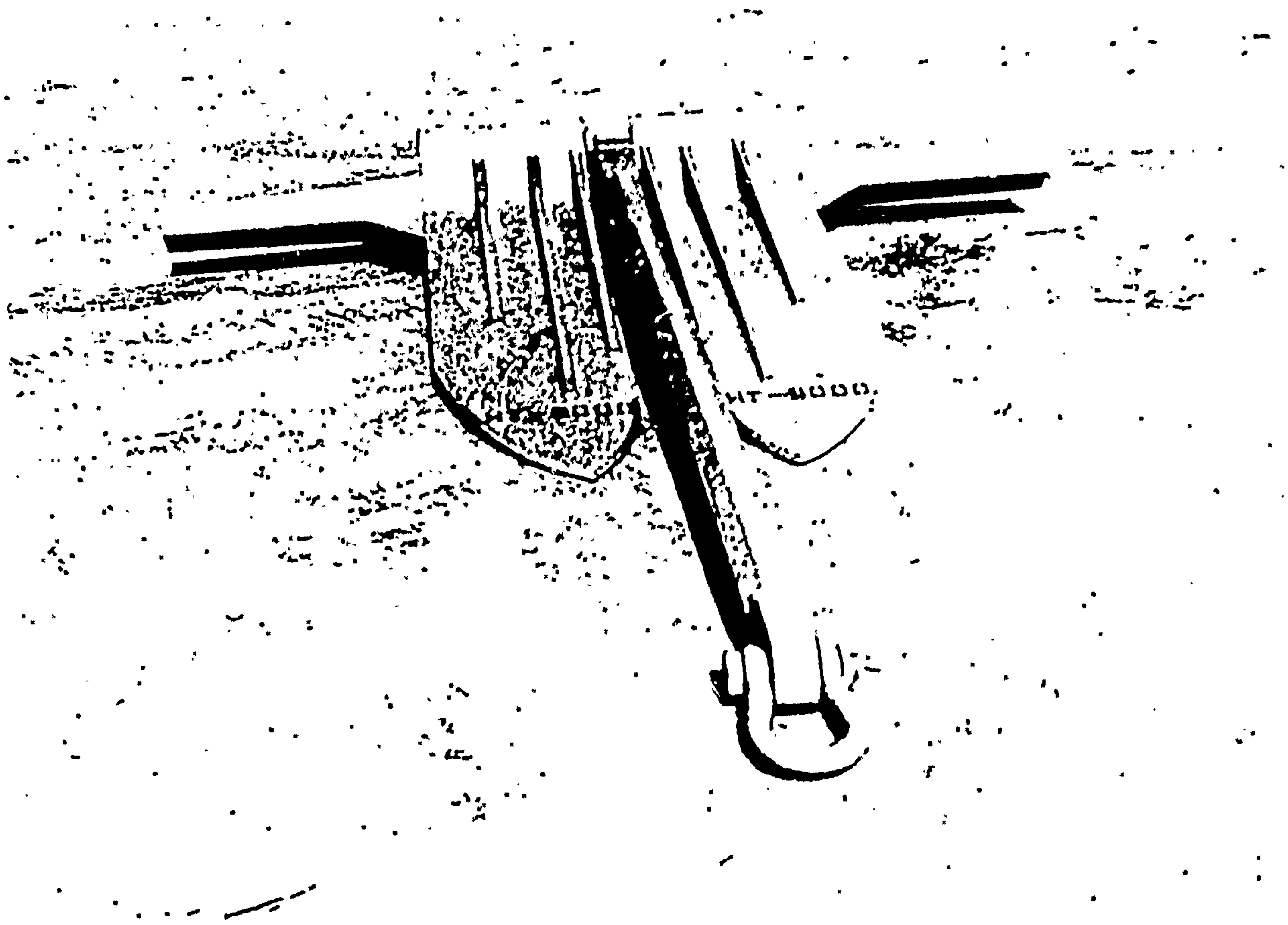


Figure 8. 9000-lb BuDocks STATO mooring anchor.

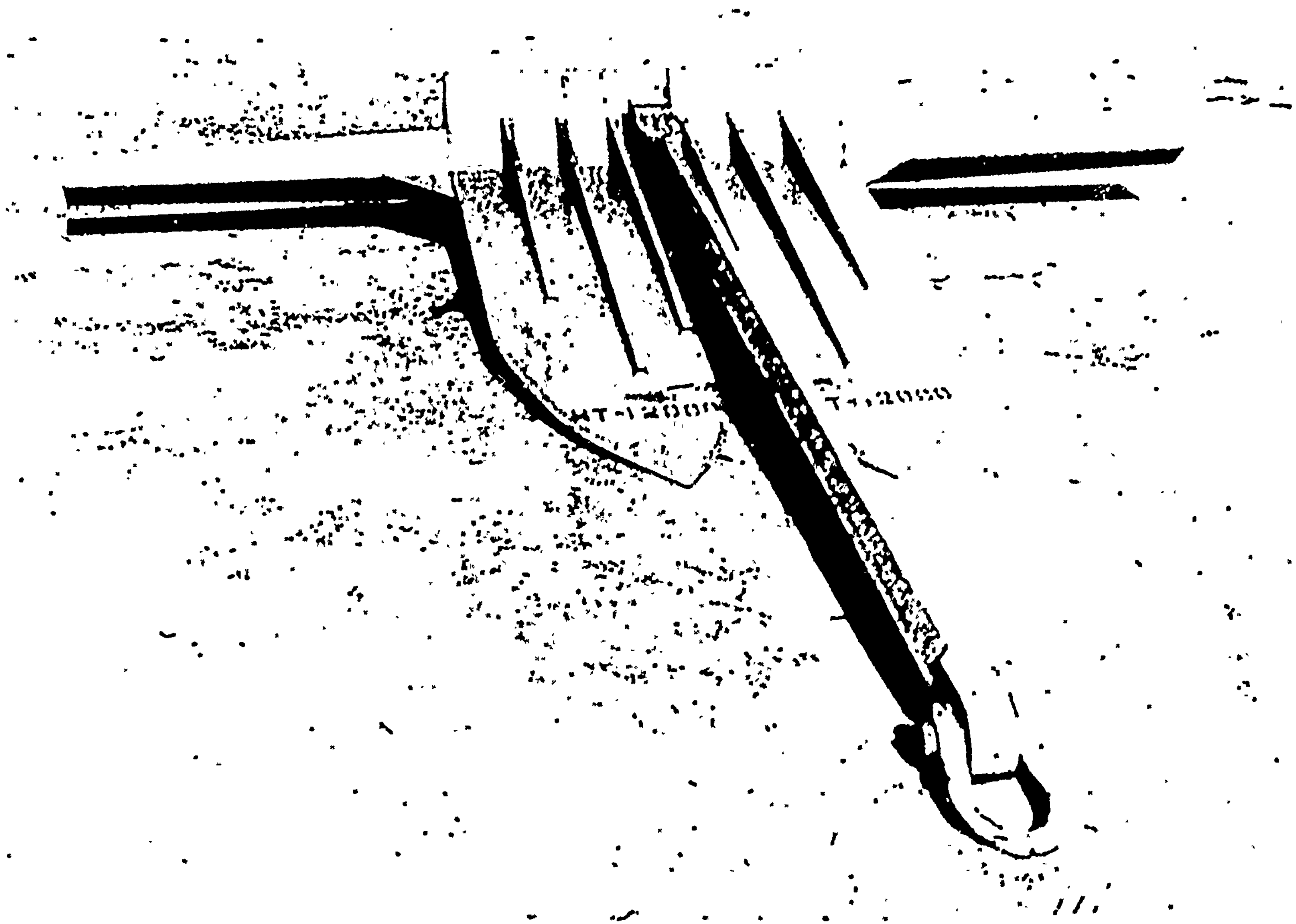


Figure 9. 12000-lb BuDocks STATO mooring anchor.

Table II. Holding Power Data of BuDocks STATO Mooring Anchors In Sand Bottom

Anchor Weight lbs	Proof Load lbs	Average holding power kips Length of Drag					Chain Angle Degrees	HP/wt ratio	Avg Break-out Force kips	Depth of Imbed-ment ft	
		50 ft	100 ft	150 ft	200 ft	250 ft				50 ft	End
200	9,000	9.6	—	—	—	—	0	48.1	5.2	4.4	5.2
200		8.6	—	—	—	—	6	43.0	4.8	3.6	4.0
200		3.0	2.6	2.7	2.6	2.9	12	15.0	1.4	—	2.4
3,000	90,000	69.7	86.7	—	—	—	0	23.2	33.0	5.2	7.4
3,000		65.9	94.1	—	—	—	6	20.9	30.2	—	7.4
3,000		46.6	46.2	44.8	45.4	47.9	12	12.2	12.5	—	3.3
6,000	180,000	122.8	183.4	—	—	—	0	20.5	50.8	4.0	6.8
6,000		116.2	176.3	—	—	—	6	19.3	48.0	—	6.0
6,000		92.7	179.1	—	—	—	12	15.5	47.0	—	5.0
9,000	270,000	199.8	271.1	—	—	—	0	22.2	83.2	3.8	5.8
9,000		110.5	102.8	104.9	107.5	114.4	6	12.3	38.7	—	3.3
9,000		103.7	106.6	107.9	108.8	98.6	12	11.5	33.3	—	2.3
12,000	315,000	235.8	314.9	—	—	—	0	19.6	131.5	4.3	5.8
12,000		170.1	169.9	165.2	161.9	162.5	6	14.2	88.9	—	3.8
12,000		142.6	154.2	168.1	161.7	157.6	12	11.9	85.5	—	4.0

Figure 10. Six part line reeved between the test barges. View is looking towards the beached or anchor barge during sand bottom tests.

rope, which was reeved through sheaves mounted on the two barges to form the six-part line, (Figure 10). One of the 5 by 12 pontoon barges was anchored with two 30,000 lb Navy stockless anchors (additional anchors were required in mud bottom tests) and the other barge was attached to the test anchor with suitable lengths of anchor chain.

The Commanding Officer, San Francisco Naval Shipyard, Hunters Point, California assigned an area to the Laboratory (approximately 150 ft by 300 ft adjacent to Pier 55) in which to conduct the mud bottom tests. The sand bottom test area at Port Hueneme, California was located between the harbor entrance and the west jetty. Figures 11 and 12 show general views of the barges at Hunters Point and Port Hueneme during the mud and sand bottom tests. In Figure 11 the test anchor is located beneath the buoy between the two farthest barges while the buoy in the right foreground locates one of the 30,000 lb stockless anchors used to hold the barges in position. The anchors were dragged at a speed to 2 ft per minute.

The warping tug winch was used to break the test anchor loose from the bottom after a test pull and to reset it for the next pulls. The force required to break the test anchor loose from the sand and mud was measured with a Martin-Decker strain gage on the warping tug winch line. The lifting force was applied to the anchor shank through a cable attached to a buoy and the depth of anchor burial was measured by means of this cable.

SOIL ANALYSIS - SAND

The soil analysis made during the initial sand tests (1950) was used as representative of the soil conditions existing during these tests. Samples were analyzed by the Soils Laboratory at BuDocks and an excellent evaluation of the interaction of the anchor and soil was made by BuDocks personnel. This report is contained in Appendix B. The mechanical soil analysis indicated 95% sand particles and 5% gravel; 92% of the sand was less than 0.6 mm in size (Sieve size 28).

SAND BOTTOM ANCHOR TESTS (PORT HUENEME)

With the wedge inserts installed to reduce the fluke angle to 34 degrees, each anchor was pulled at chain angles of 0-, 6-, and 12-degrees. The chain angle is the angle subtended by the chain and sea bottom at the anchor shackle and is computed on the basis of a catenary curve by the method shown in Appendix C.

Figure 11. Mud bottom test site in San Francisco Bay. Buoy in right foreground locates one 30,000-lb Navy Stockless anchor.

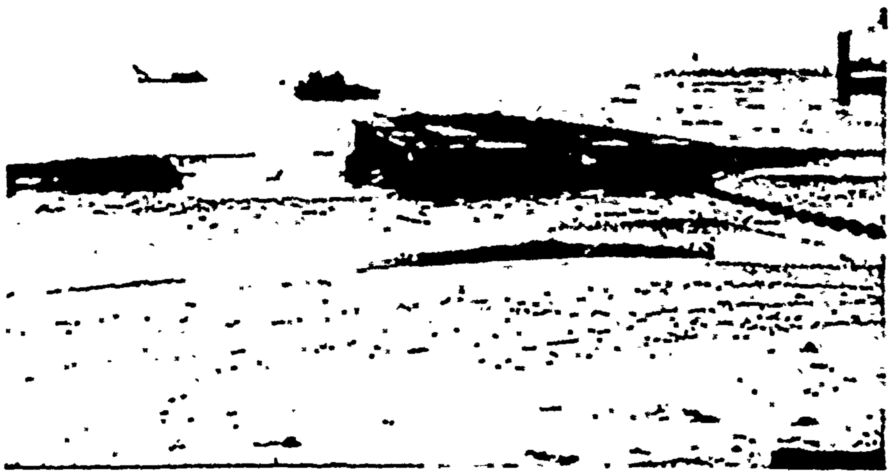


Figure 12. Test apparatus for conducting the anchor tests in sand at Port Hueneme. Anchor being tested is located by buoy at far end of barges.

Table III shows the chain sizes and lengths used to test the STATO anchors at the various chain angles. Six test pulls were conducted at each chain angle for each anchor at a rate of drag of 2 ft per min. The holding powers of the anchors were recorded at 5-ft intervals of drag for a distance of 250 ft, thus providing data for plotting a curve of anchor holding powers versus distance of drag. In this report, the ratio of the holding power to anchor weight in air, H^D/wt, was taken after the anchor dragged 50 ft. Longer drag distances will produce a larger holding power, however, a distance of 50 ft was set by BuDocks as the limit of allowable travel for moorings in confined locations. In order to eliminate possible costly repairs and delays, the anchors were limited to a drag distance which would not produce a holding power greater than their proof load, although in one instance the 12,000 lb anchor was unintentionally loaded to failure as described later. This limitation restricted the length of drag on all five STATO anchors at 0-degree chain angle to less than 250 ft.

The vertical force required to break the test anchors loose from the bottom at the end of each test pull (Figure 13) was measured with a strain gage mounted on the warping tug winch line (Figure 14). The depth of water was approximately 25 ft at the test site. Table II lists the five STATO mooring anchors average holding power at the 50 ft drag point, weight to holding power ratio, depth of burial, proof load, and the average breakout force at the end of the tests. Graphs of the test results for the average of six test pulls of each anchor at chain angles of 0, 6 and 12 degrees are shown in Figures 15 through 19. The average holding power of each STATO anchor dragged at a 0-degree chain angle for 50 ft, and to the breakout point follow.

Anchor Weight (Pounds)	Holding Power (Pounds)	
	50-ft Drag Point	Point of Breakout
200	9,600	9,600
3,000	69,700	86,700
6,000	122,800	183,400
9,000	199,800	271,100
12,000	235,800	314,900

Operational procedures required that the barges be anchored by the test anchors during the night. The test area was partially sheltered by two jettys at the Port Hueneme harbor entrance, however during stormy weather accompanied by southerly winds the test area becomes exceedingly rough. One such storm occurred during the night while the 12,000 lb anchor was under test. The following day

Table III. Anchor Chain Design

Anchor Weight Pounds	Chain Size Inches		Chain Length feet					
			SAND			MUD		
	Sand	Mud	0°	6°	12°	0°	6°	12°
200	3/4*	1	255	165	105	255	165	105
3,000	1-5/8	1-3/4	390	226	120	360	240	135
6,000	2-3/4	2-3/4	330	240	120	360	210	140
9,000	2-3/4	2-3/4	450	240	150	440	255	150
12,000	2-3/4	2-3/4	490	265	135	490	270	165

* wire rope

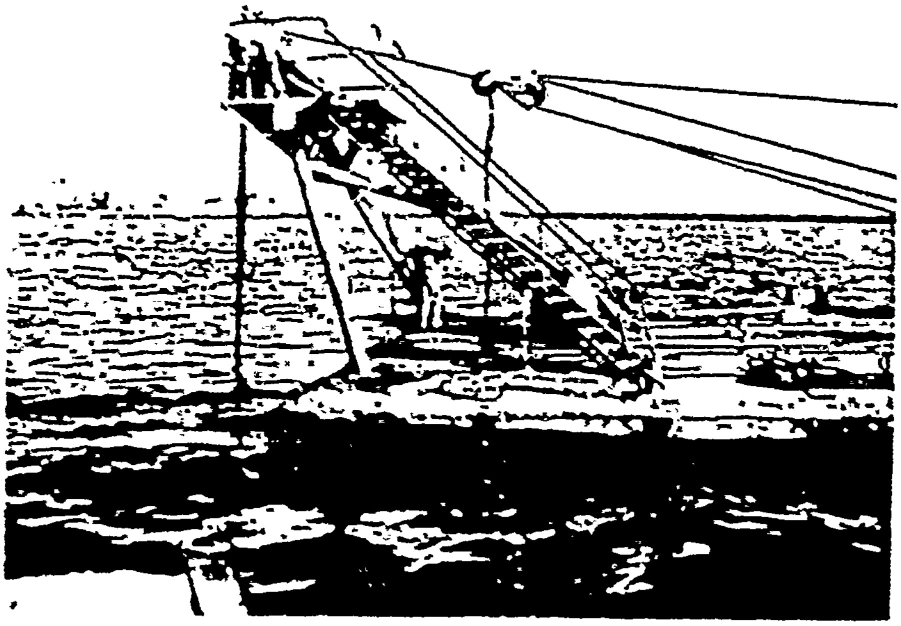


Figure 13. View of warping tug making break-out test, free board at bow of tug is normally 3-1/2 ft.

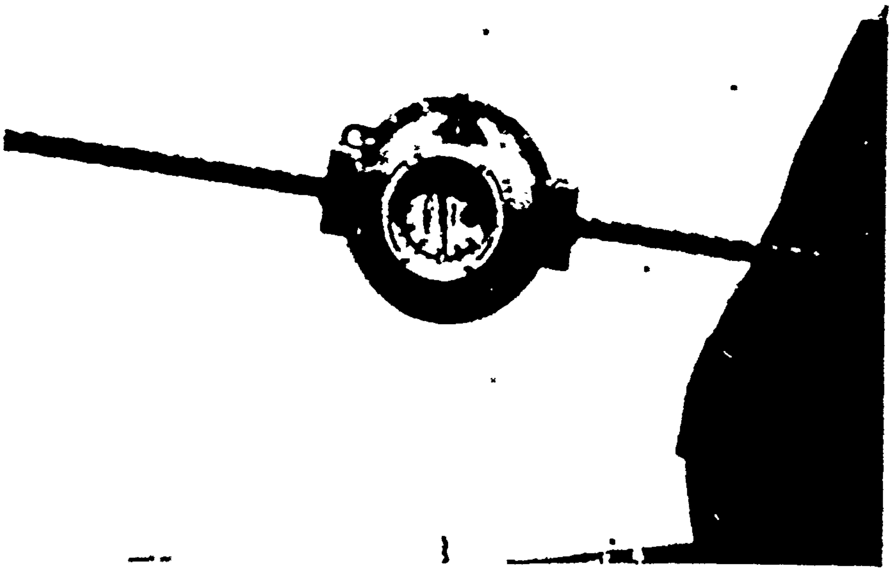


Figure 14. Strain gage used to measure break-out force of anchors.

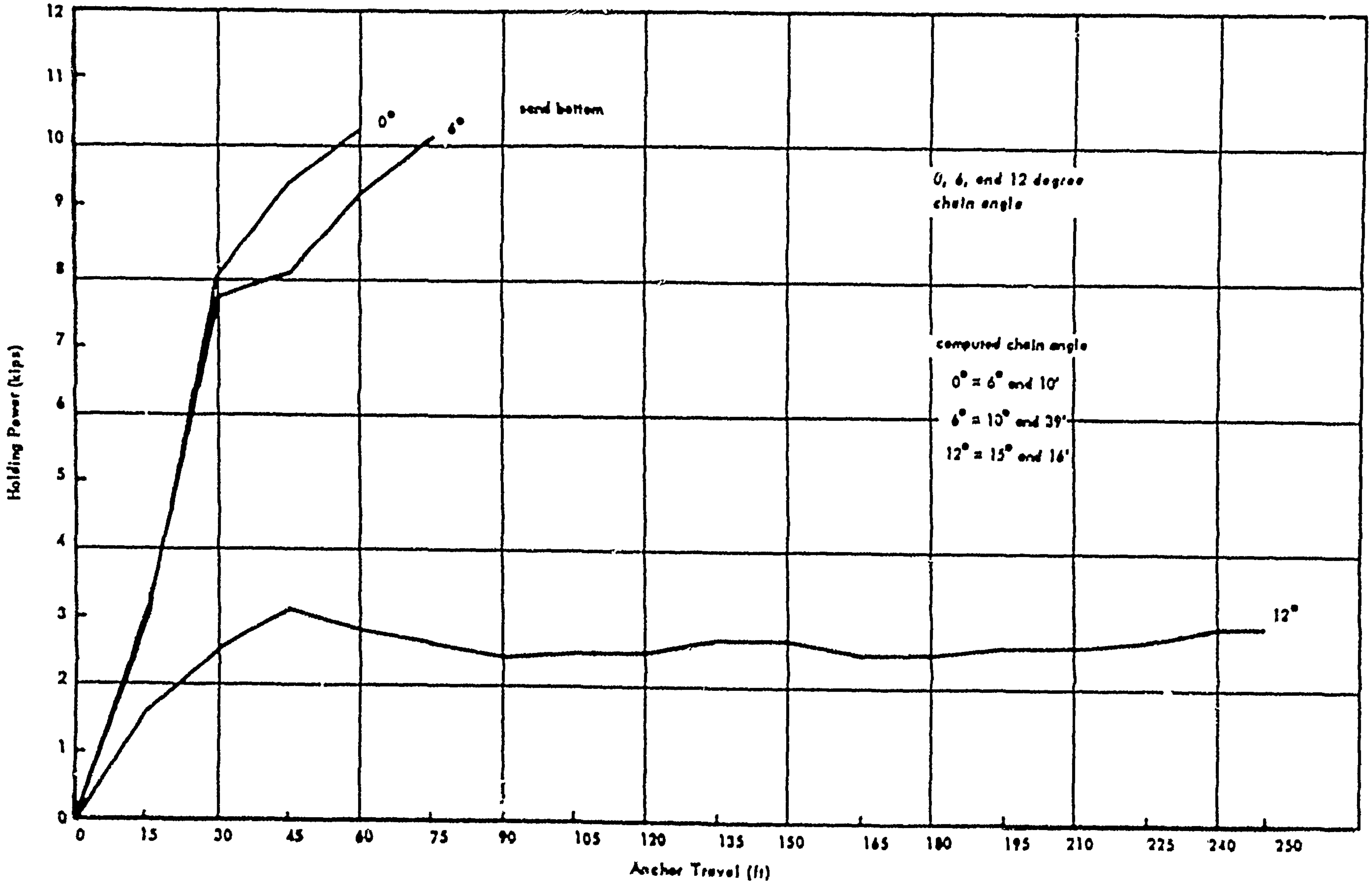


Figure 15. Graph of average test pulls on 200-lb STATO mooring anchor.

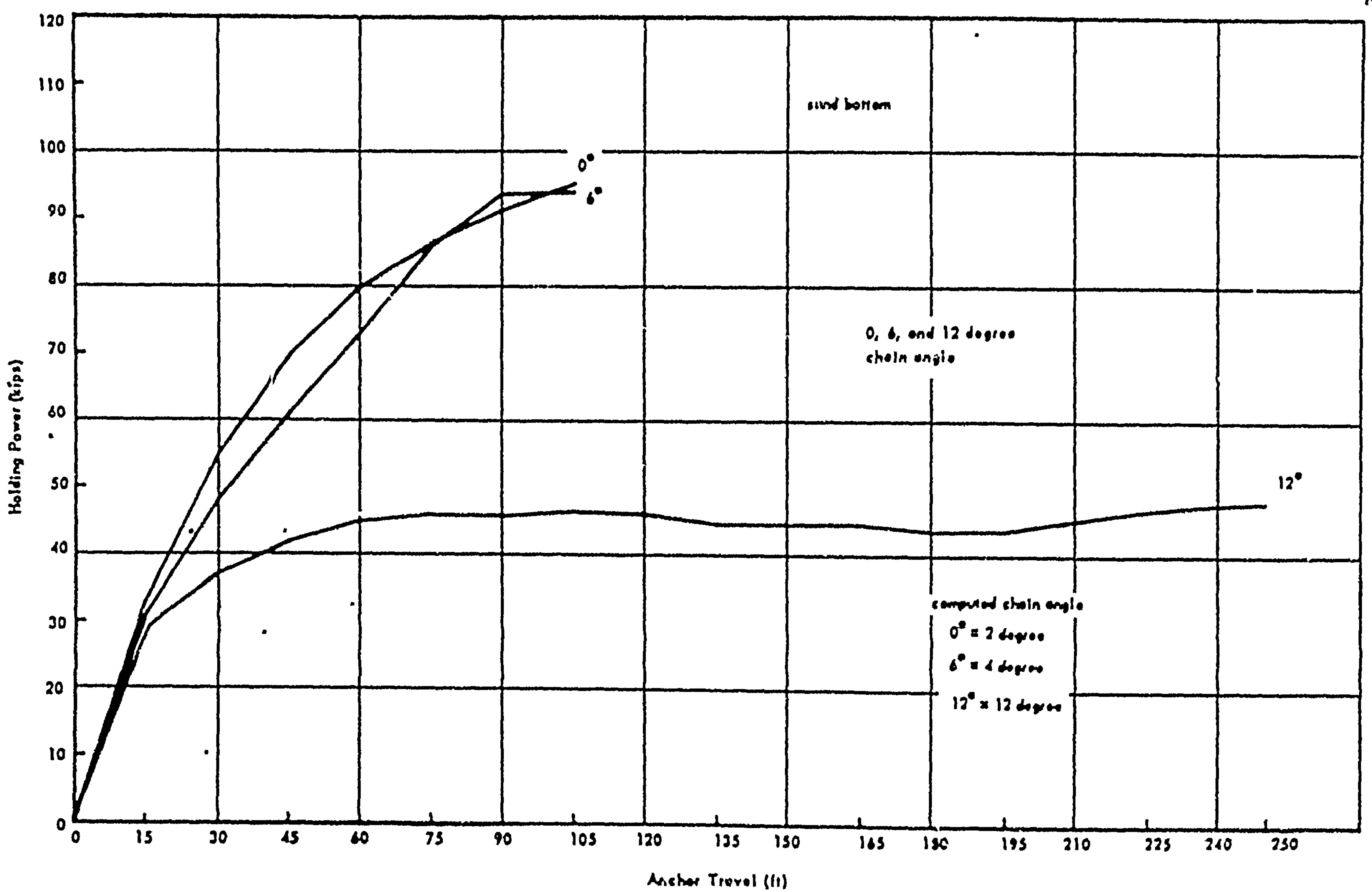


Figure 16. Graph of average test pulls on 3000-lb STATO mooring anchor.

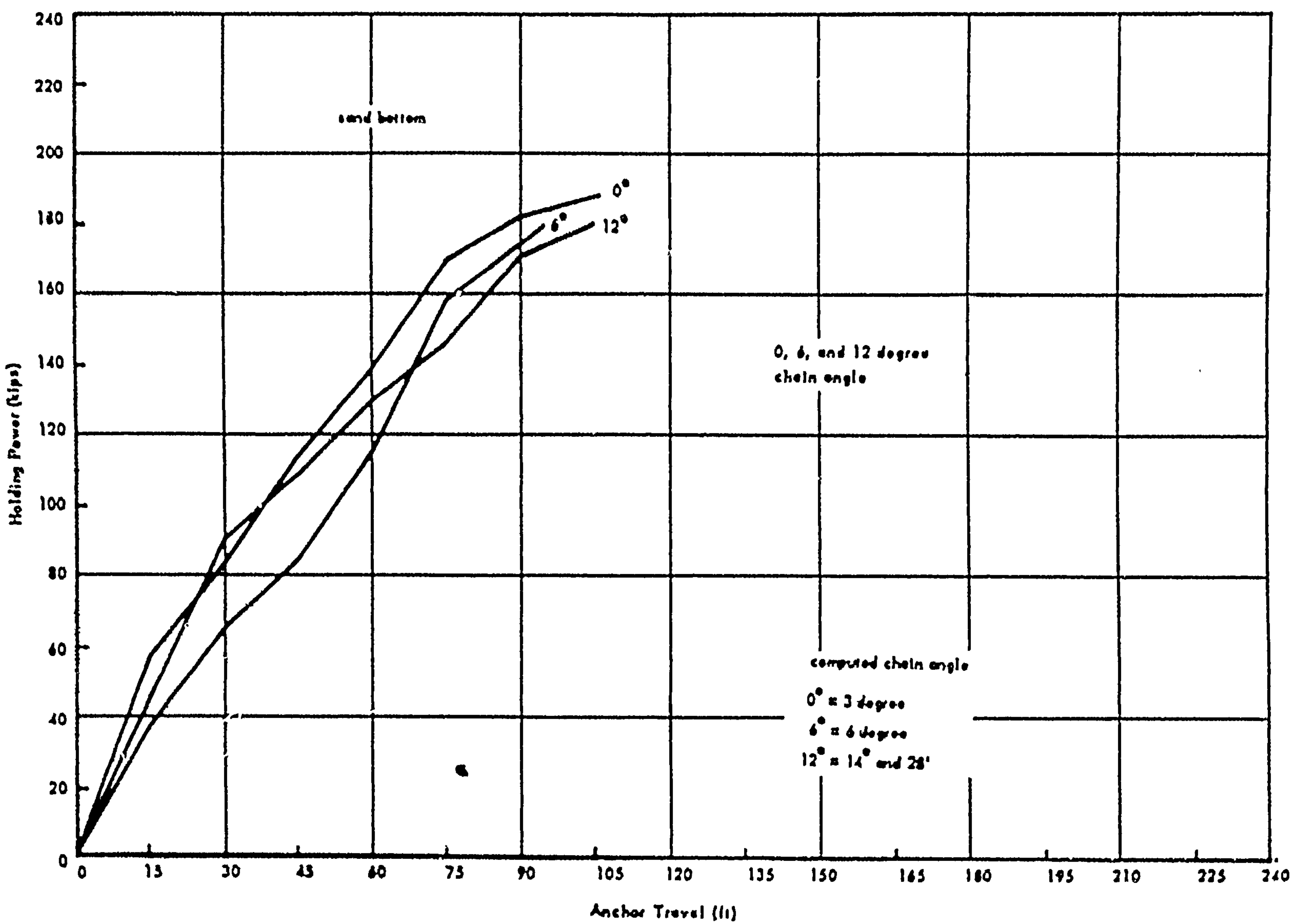


Figure 17. Graph of average test pulls on 6000-lb STATO mooring anchor.

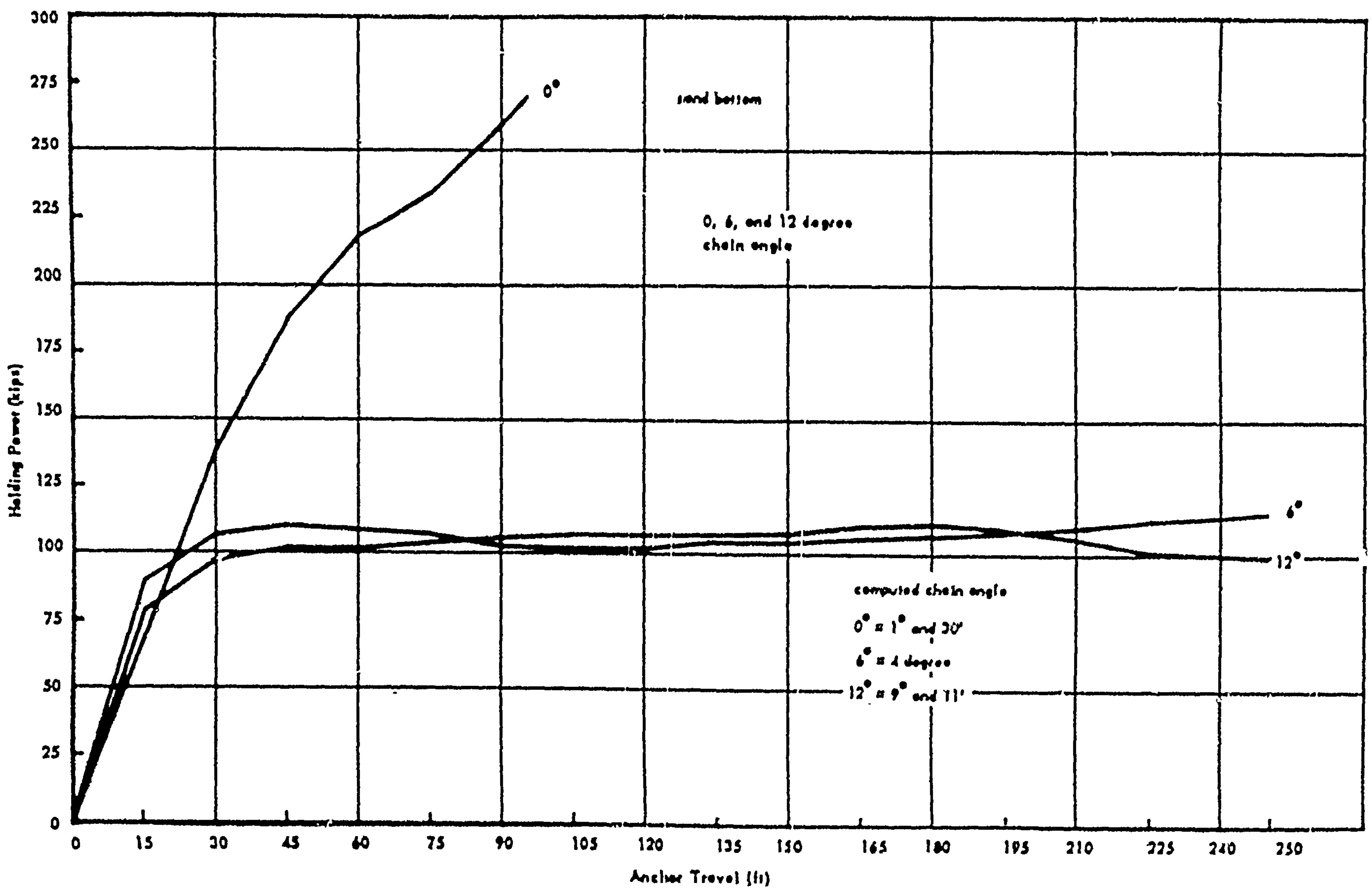


Figure 18. Graph of average test pulls on 9000-lb STATO mooring anchor.

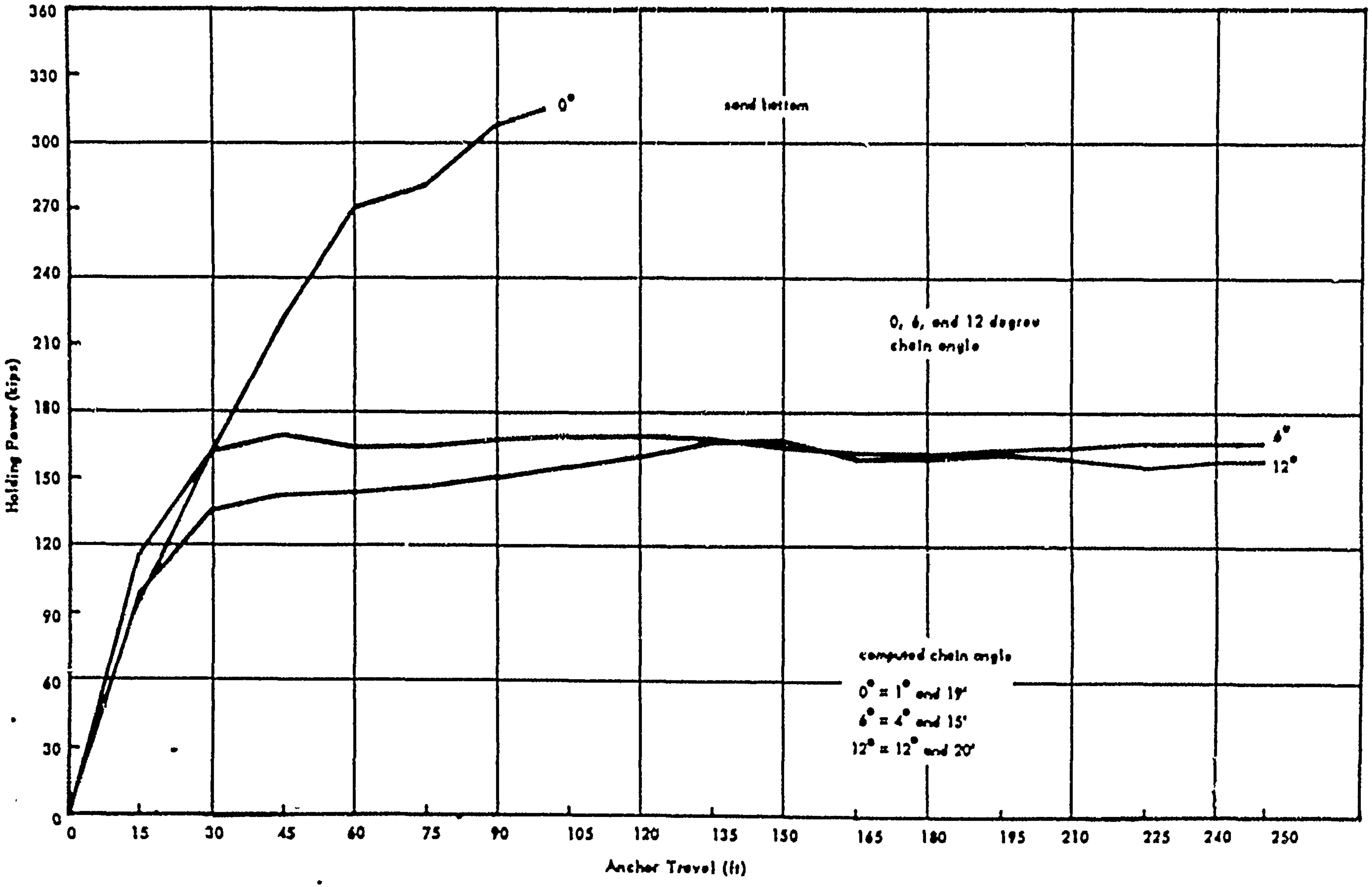


Figure 19. Graph of average test pulls on 12000-lb STATO mooring anchor.

the holding power of the test anchor set by the storm was measured at 415,000 lb and upon attempting to retrieve it, the shank pulled out of the crown. All of the anchors were subsequently strengthened at the crown by the addition of small bearing blocks. See the drawings in Appendix A.

ANCHOR CHAIN TESTS - SAND (PORT HUENEME)

Test pulls of the anchor chain alone were conducted to determine the resistance developed by the chain dragging through the sand bottom. The average holding power of 450 ft of 2-3/4-in. anchor chain was 32.4 kips. The anchor chain connects the anchor to the ship, but is useful primarily to flatten the angle at the anchor shackle and to absorb shocks as the chain catenary dips and straightens.

SOIL ANALYSIS - MUD

While the term "mud" is not descriptive of a soil in terms of texture, it will be used in this report as it is commonly used to describe soil mixtures based on composition and structure.

A 2-in. diameter Porter sampling device was used to take samples of soil down to a depth of 30 ft in the path of the anchor test pulls and the soil was analyzed in the laboratory at the Twelfth Naval District Public Works Office, San Bruno, California. The samples were tested for liquid and plastic limits, specific gravity, unconfined compression and consolidation (Tables IV, V and Figures 20 and 21) and mechanical analysis (Figure 22). Unconfined compression tests were performed on the samples at their natural water content and the rate of strain was maintained between 1/2 percent to 1-1/2 percent per minute. The type of failure is shown in Figure 23. For the consolidation tests, the field specimens were placed in a fixed-ring consolidation device, seated firmly, and loaded in increments as shown in Table IV. Direct shear tests were made on the undisturbed specimens taken with the Porter sampler, in a consolidation-quick condition, at a constant displacement of .05-in. per minute (Figure 24). Shear tests were made on samples taken at depths of 19 ft and 25 ft below mud line. Triaxial shear data were obtained by conducting unconsolidated undrained tests on samples taken with the Porter sampler (Figures 25 and 26). The test lateral pressure, measured with a proof ring type stressometer, was applied instantaneously and the specimen sheared quickly. Volume changes were noted during the tests. Rate of strain was equal to about 1 percent per minute.

Table IV. Soil Analysis Data - Mud Bottom

Hole no.	Sample no.	Elev. depth	Unit weight lb per cu/ft		Moist content (% dry weight)	Unconfined compression (ton/sq ft)
			wet	dry		
1	1	4	87.3	45.9	90.0	0.08
	2	10.6	91.5	48.6	88.7	0.09
	3	10.10	81.9	43.5	88.7	0.08
	4	12	91.3	48.5	8[illegible]	0.08
	5	17.4	-	-	86.1	0.08
	6	17.8	87.2	[illegible].9	86.1	0.09
	7	18	-	-	86.1	-
	8	23.4	91.2	50.6	80.2	0.10
	9	23.8	90.8	50.4	80.2	0.09
	10	24	92.8	51.5	80.2	0.10
	11	29.4	96.5	57.6	67.4	0.13
	12	29.8	97.1	58.0	67.4	0.17
2	1	9.11	91.5	49.1	86.5	
	2	10	115.2	62.7	83.7	
	3	10.1	101.4	52.6	92.8	
	4	10.6	92.1	48.2	91.3	
	5	13.11	104.4	55.2	89.0	
	6	14	102.9	56.3	82.9	
	7	14.5	93.8	50.2	86.7	
	8	14.6	101.7	54.7	85.8	
3	2	9.4	89.6	48.2	86.0	0.06
	3	9.8	89.2	48.0	86.0	0.06
	4	10	90.7	48.8	86.0	0.09
	5	15.4	90.3	49.6	81.9	0.11
	6	15.8	92.5	50.9	81.9	0.09
	7	16	97.5	53.6	81.9	0.11
	8	21.4	89.8	49.7	86.8	0.12
	9	21.8	88.6	49.0	86.8	0.10
	10	22	92.0	50.9	86.8	0.11
	11	26.4	97.0	59.0	64.5	0.21
	12	26.8	97.1	59.0	64.5	0.16
4	3	12	92.3	54.5	69.5	0.13
	6	18	99.3	58.6	69.5	0.24
	9	24	99.4	62.6	58.8	0.22
	12	30	95.2	59.9	58.8	0.31

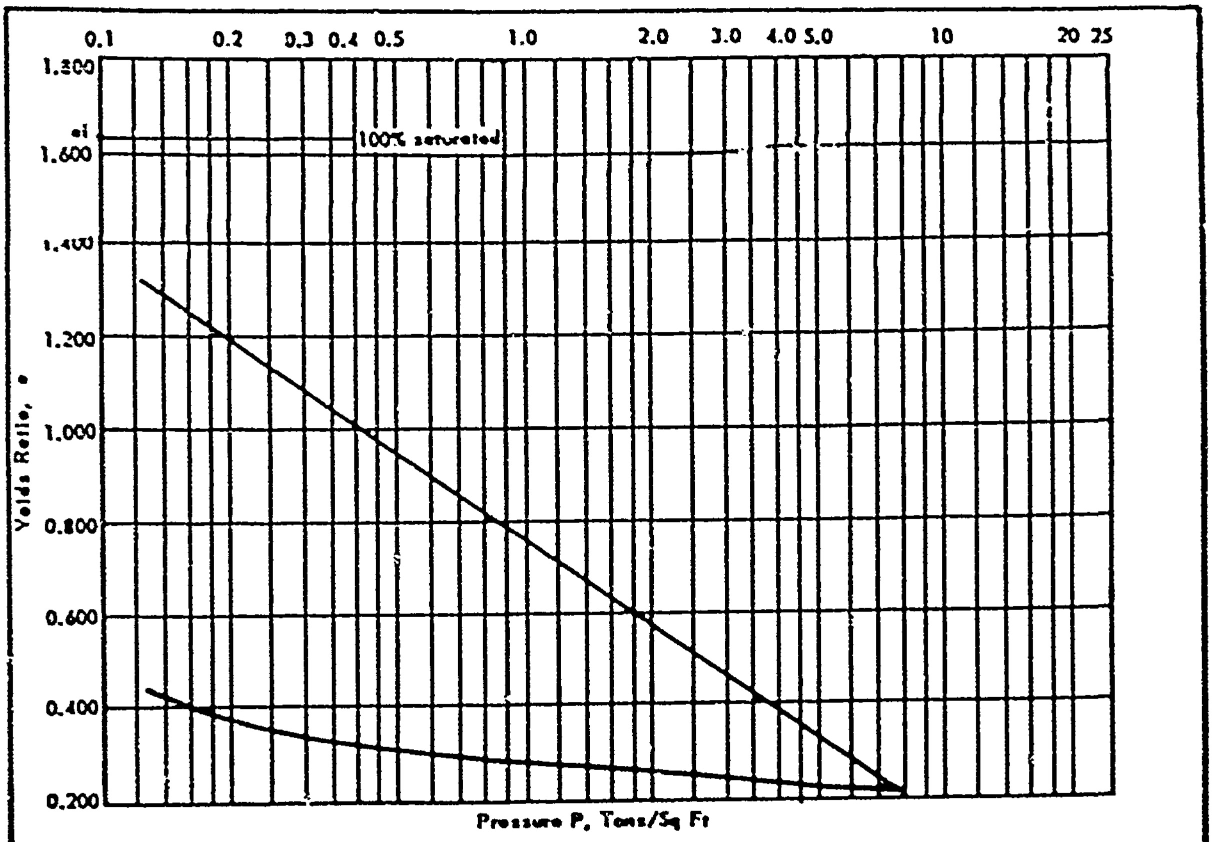
Table IV. (Cont'd)

Hole no.	Sample no.	Elev. depth	Unit weight lb per cu/ft		Moist content (% dry weight)	Unconfined compression (ton/sq ft)
			wet	dry		
5	3	12	95.5	57.2	66.9	0.11
	6	18	95.4	57.2	66.9	0.15
	9	24	97.9	62.2	57.5	0.13
	12	30	94.1	56.0	68.0	0.24
6	2	7	91.1	50.4	80.6	0.04
	5	12	91.0	50.4	80.6	0.11
	7	17.8	95.1	55.7	70.8	0.11
	10	23.8	94.2	55.2	70.8	0.11
	13	13	30	64.4	53.6	0.26
7	3	11.8	90.0	51.6	74.3	0.08
	7	18.0	94.4	54.2	74.3	0.07
	9	23.8	91.4	52.4	74.3	0.11
	13	30	94.9	61.0	55.6	0.12
8	3	11.8	89.4	52.5	70.3	0.06
	7	18	91.8	53.9	70.3	0.10
	10	24	93.8	58.6	60.2	0.13
	13	30	100.3	62.6	60.2	0.21

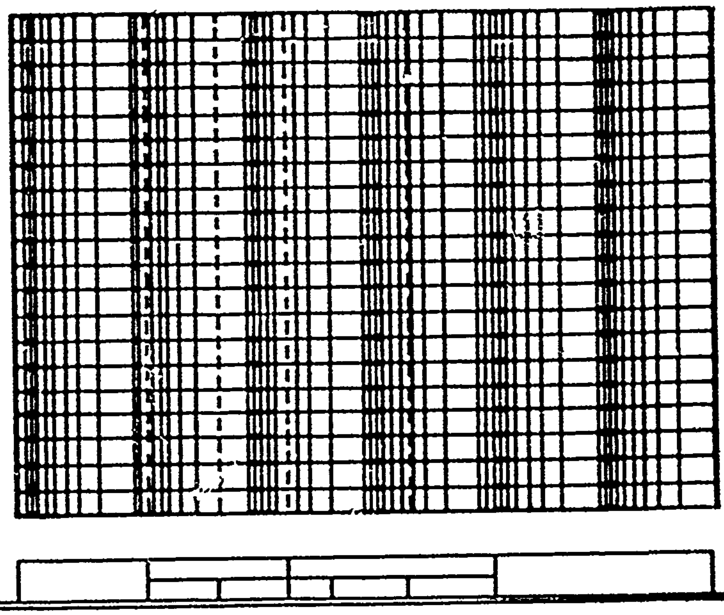
Table V. Soil Consolidation Data

Hole no.	Sample no.	Elev. depth	Consolidation % original ht (ton/sq ft)							Direct cohesion (psi)	Shear angle of internal friction
			1/8	1/4	1/2	1	2	4	8		
2	2	19-21	13.0	19.9	27.1	33.6	41.1	48.0	54.5		
	5	23-25	8.6	13.5	19.5	26.2	33.0	39.8	46.1		
	3	23-25								360	15°
	6	19-21								360	15°
	8	23-25								360	15°

Hole No. 1 composite of samples 2, 3, 4 – liquid limit 55; plasticity index 29
Hole No. 1 composite of samples 11, 12, 13. " " 50; " " 22
Hole No. 2 sample No. 4 – liquid limit 54; plasticity index 29
Hole No. 6 composite of samples 2, 5, 7, 10–liquid limit 42; plasticity index 18



TEST DATA	
Type of Specimen	UNDISTURBED
Overburden Pressure, P_o	0.17 tons/sq ft
Preconsol Pressure, P_c	NEG tons/sq ft
Compression Index, C_c	0.6101
Initial Ht. 0.50 in.	Diam. 2.50 in.
Initial Saturation, S_o %	100
Final Saturation, S_1 %	100
Initial Dry Density lbs/cu ft	62.7
Initial Water Content, W_o %	83.7



Remarks

Classification CH (fat clay)

LL 54	G_1 2.67
PL 25	D_{10} 0.07 MM

Project SFNS Anchor Test Site

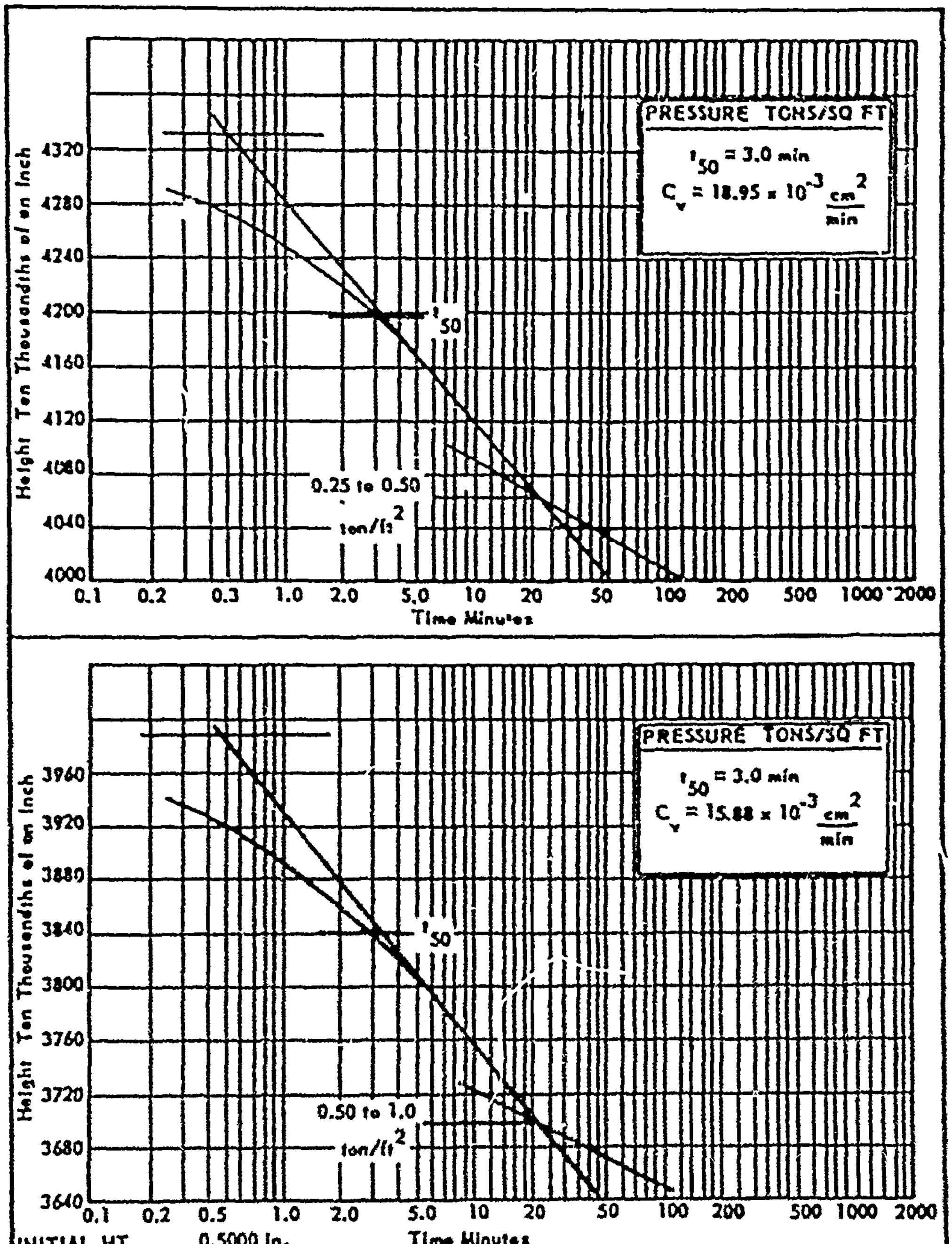
Lab # 10015

Area

Boring No. 2	Sample No. 2
Depth 48'	Date 5 Aug 1957

CONSOLIDATION TEST REPORT

Figure 20. Consolidation data - mud bottom.



INITIAL HT 0.5000 In.			
PROJECT SFHS Anchor Test Site			Lab #10015
AREA			
BORING 2	SAMPLE NO 2	DEPTH 48'	DATE 5 Aug 1957
CONSOLIDATION TEST-TIME CURVES			

Figure 21. Consolidation data – mud bottom.

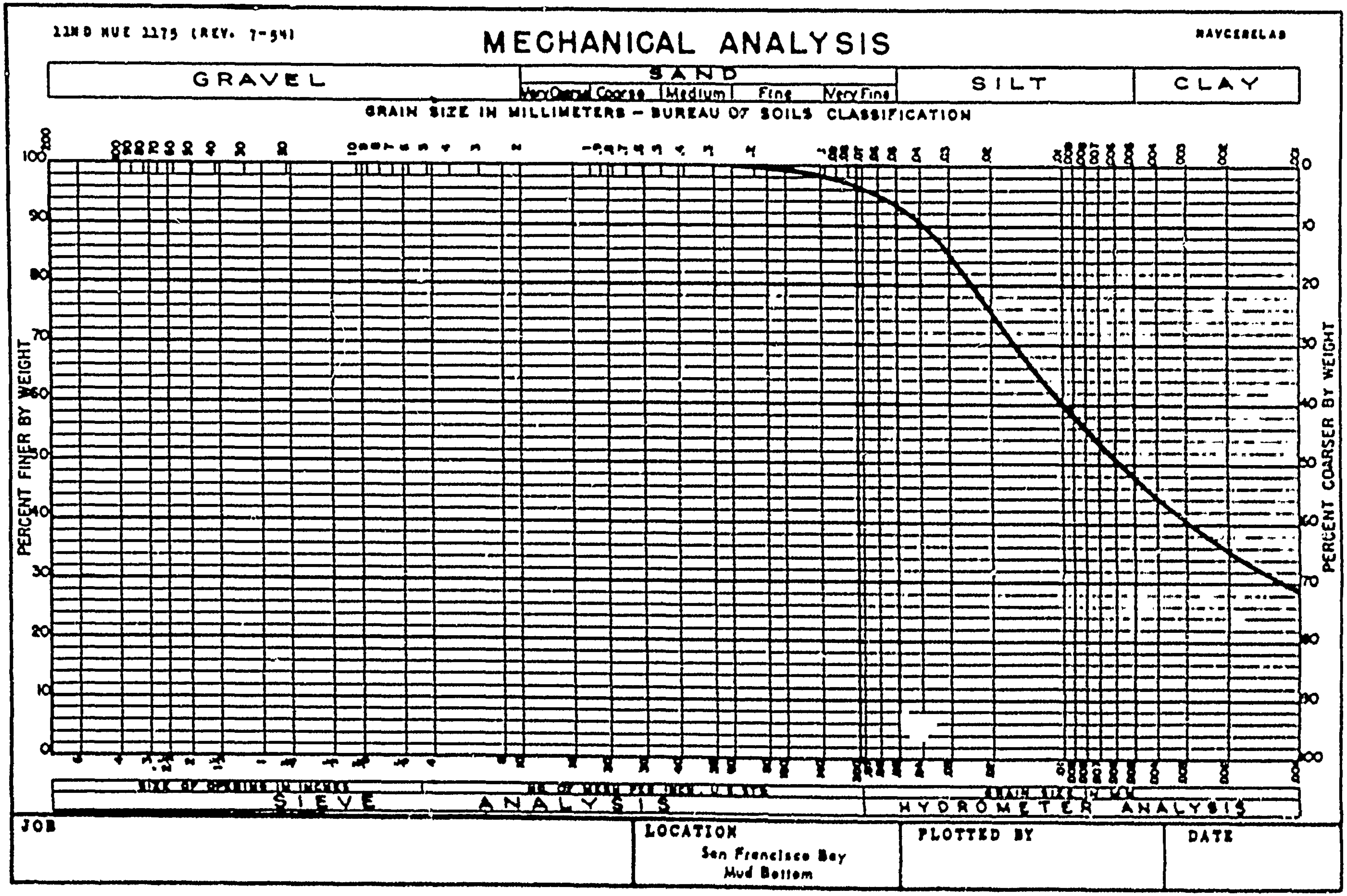


Figure 22. Mechanical analysis data - mud bottom.

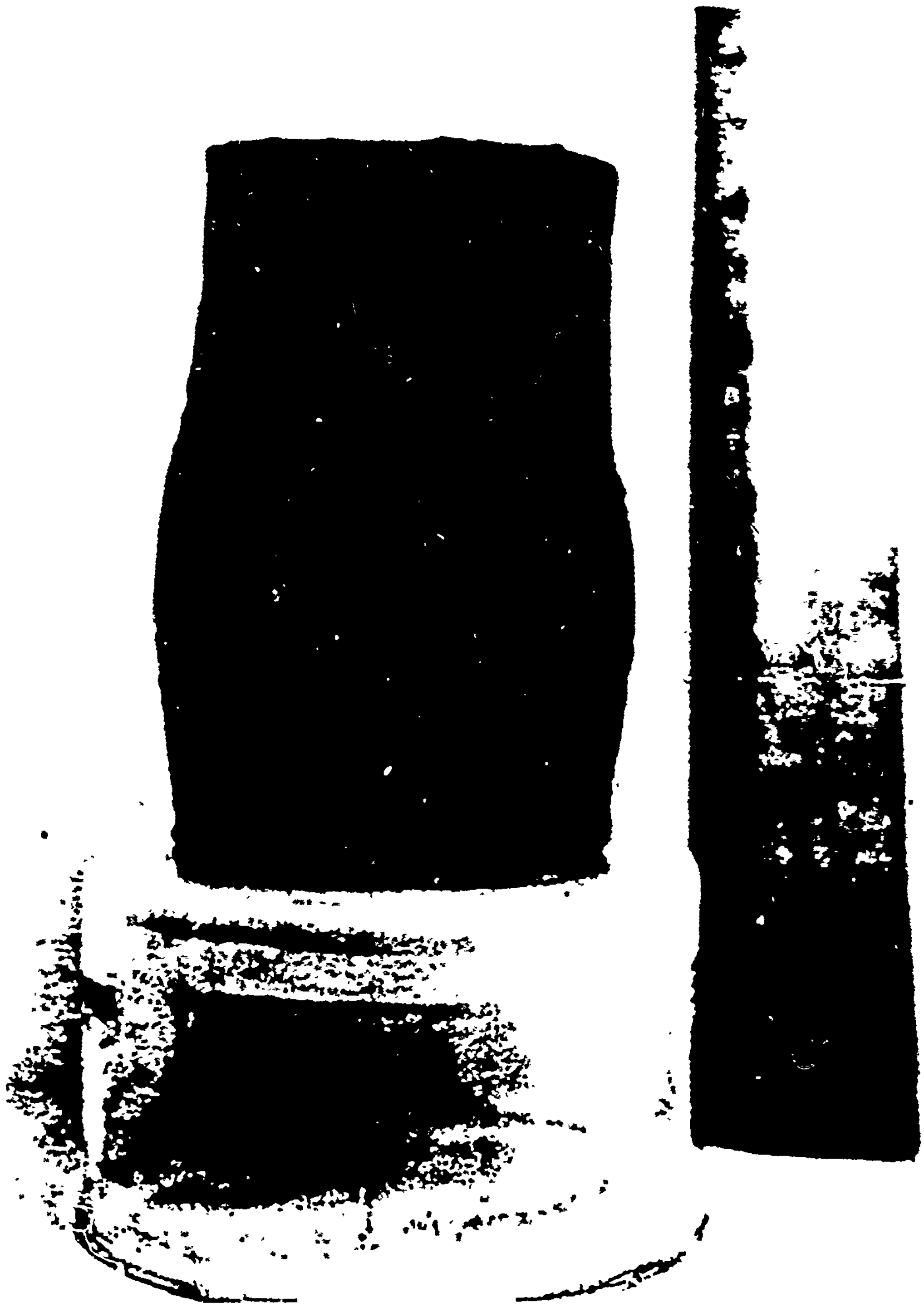
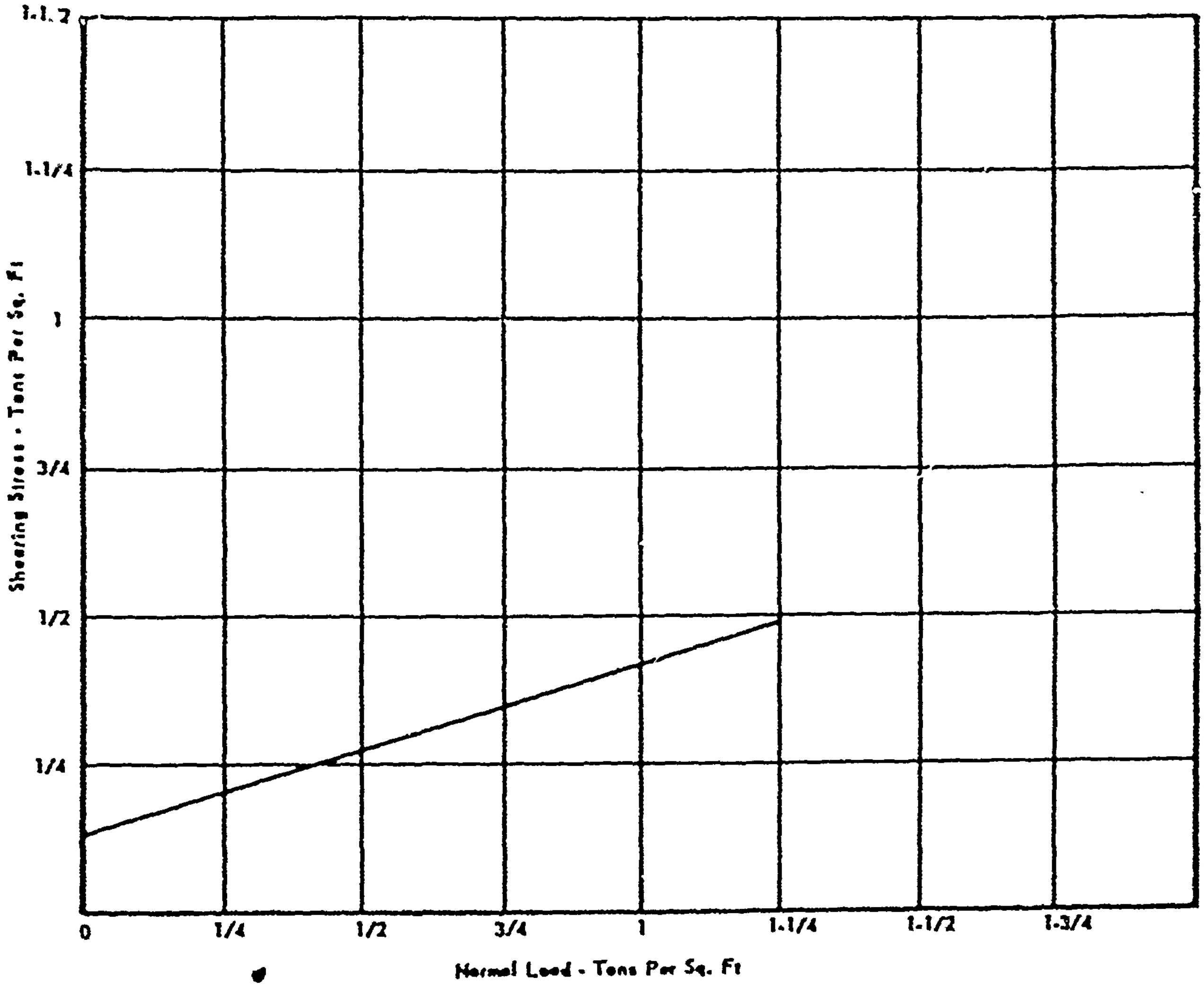
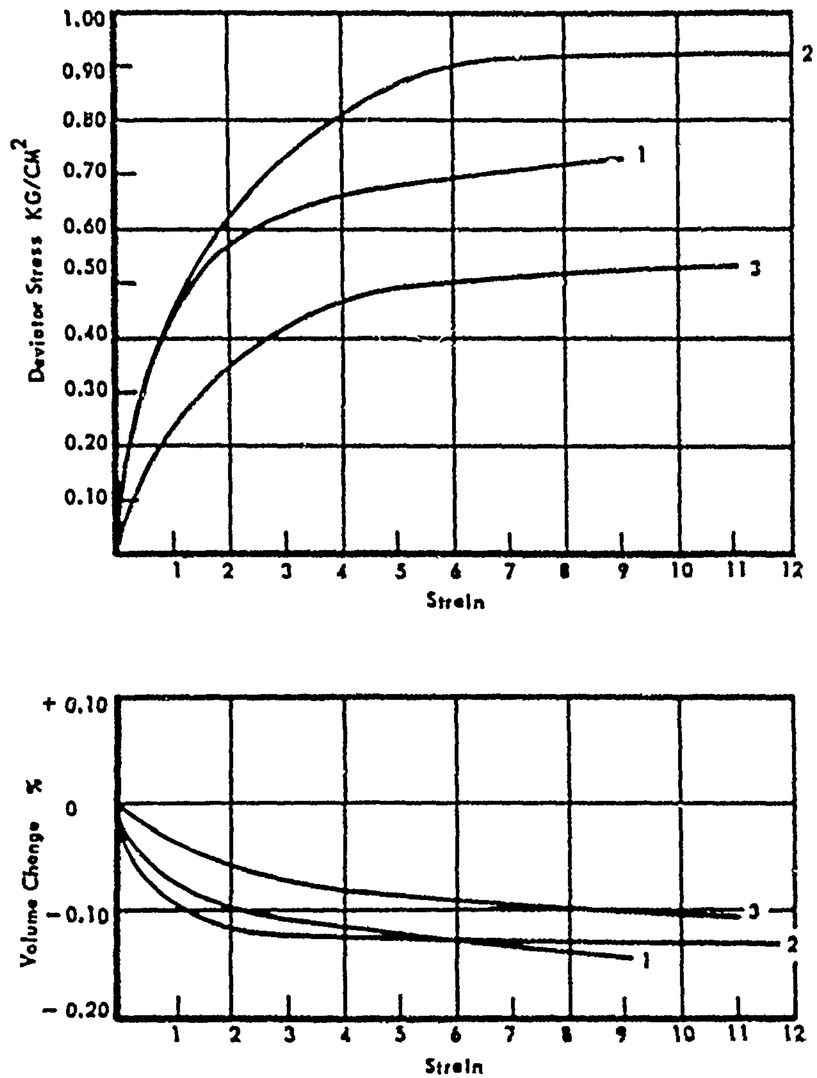


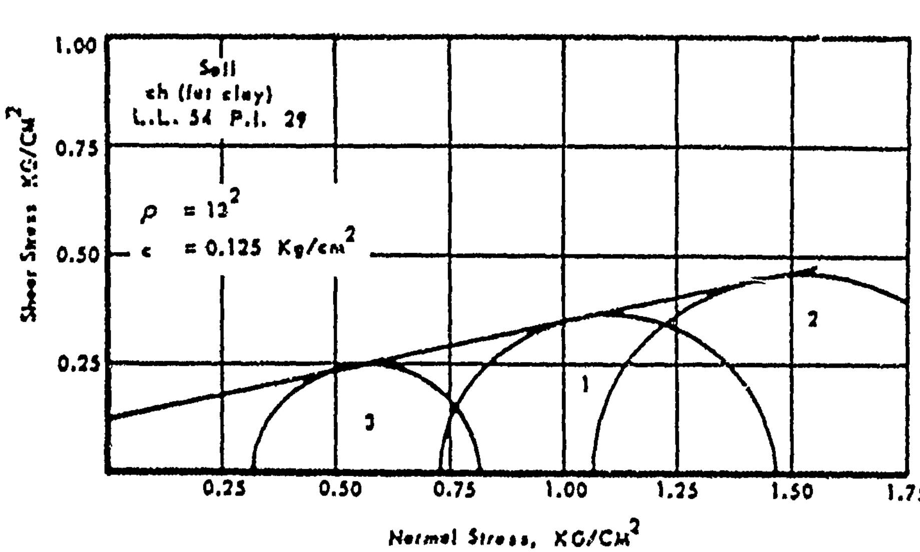
Figure 23. Unconfined compression test failure.



STATION	San Francisco Naval Shipyard	STRESS-LOAD CURVE
PROJECT	Anchor Test Site	
		C= 0.18 TONS/SQ. FT
LOCATION	#3, #6, #8	σ= 15
SAMPLE LAB NO	10015	
HOLE NO	2	
DEPTH FROM	48' TO 52'6"	
DATE: 30 July 1957		

Figure 24. Shear test data





curve no.	rate of shear: total time min	rate of shear: avr % per min	lateral pressure KG/CM²	specimen dry weight LB/CF	prepared at: moisture per cent	initial: moisture per cent	initial: saturation per cent	final: moisture per cent
1	9	1	0.705	49.1	90.1	86.5	96.0	100.0
2	12	1	1.057	48.2	92.4	91.3	98.8	100.0
3	11	1	0.352	50.2	87.3	86.7	99.3	100.0

type of test
consolidated, drained

lateral pressure method: Hydraulic

Specimen Data

ht in	dia in	maximum particle size	G	condition
5.00	2.50	0.840 mln	2.70	as sampler

project: San Francisco Naval Shipyard
anchor test area

ney
hole no. 2 s-1, s-4, s-7
depth 48'
lab no. 10015 date: 25 July 1957

Figure 25. Triaxial shear data.

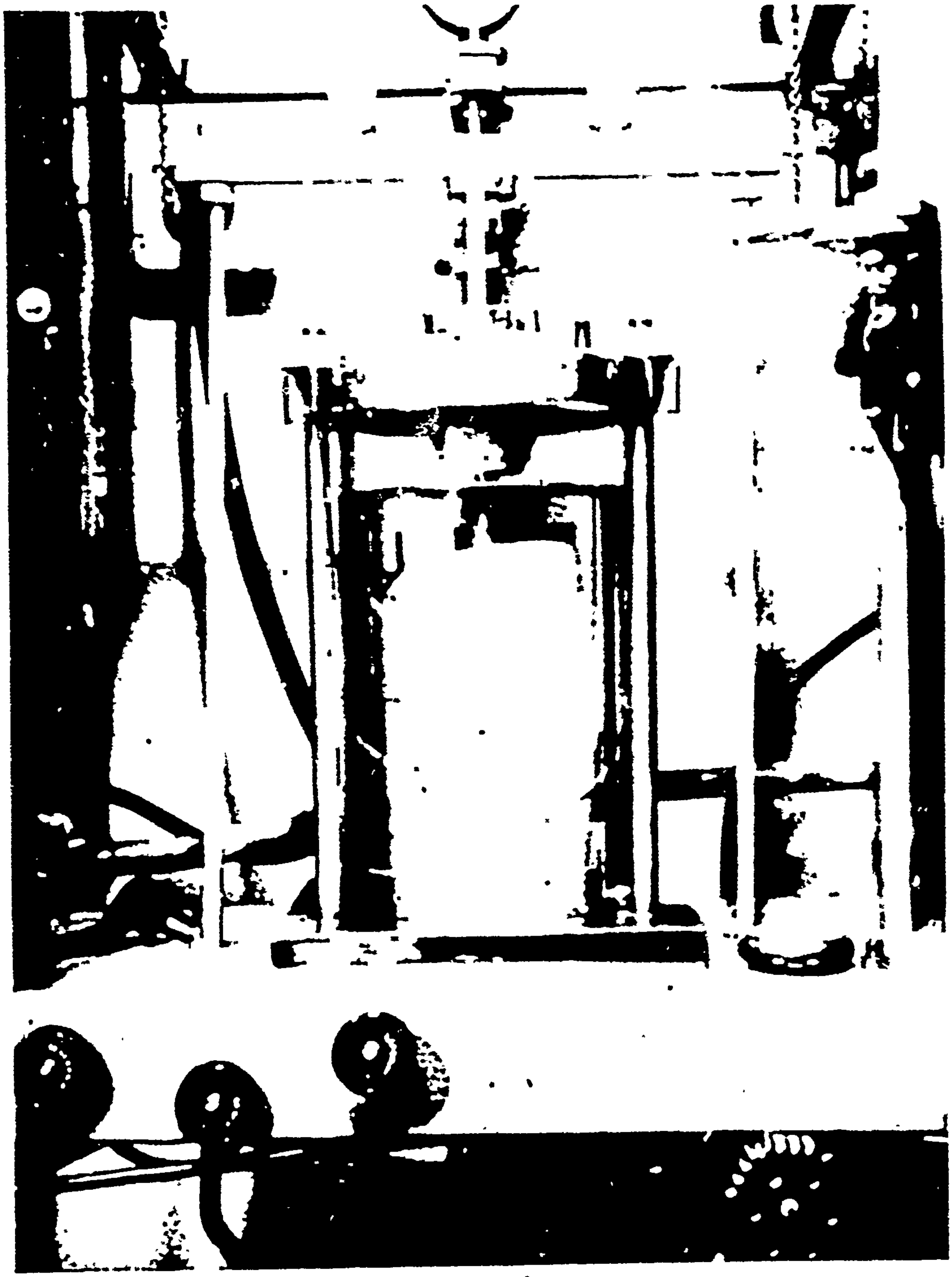


Figure 26. Triaxial shear test failure.

The soil contained approximately 50 percent clay particles with 80 percent water content, and the cohesive strength was .18 ton per square foot.

The soil at the test site was termed "mud" because the high water content in the silty clay material produced a low shear value. However, the mechanical composition of the soil showed 50 percent clay content and this indicated that at about the 22 ft depth the material would be firmer and have larger holding powers comparable to those of a "clay" bottom. The mooring anchors were so designed as to bury themselves to a considerable depth – as much as 32 ft for the 9,000 lb anchor – and therefore the resulting holding powers are not strictly comparable with "mud" bottom holding powers. However, the upper levels of the soil resemble "mud" and similarly effect the tripping and initial setting of the anchors.

MUD BOTTOM ANCHOR TESTS

The anchor test barges were towed to San Francisco Naval Shipyard, Hunters Point, California to conduct the "mud" bottom tests in San Francisco Bay. Investigations at the test site had shown the silty clay material in the bay to be 100 to 150 feet thick and the water 35 ft deep.

The anchors were readied for testing by removing the wedge inserts from the anchor shanks to permit the flukes to open to a 50-degree angle, and welding the palm extensions (Figure 27 and Y & D drawings Appendix A) on the tripping palms. The palm extensions increased the area of the tripping palms by approximately 100 percent for each anchor.

Six test pulls were made on each anchor at chain angles of 0-, 6-, and 12-degrees. The anchors were dragged for a distance of 250 ft except when the holding power reached the proof load of the anchor before this distance as it did while testing the 12,000 lb anchor at 0-degree chain angle.

During the tests on the 9,000 lb STATO anchor, the anchor barge which was secured by the 30,000 lb Stockless anchors, was dragged from its position and the 12,000 lb STATO anchor was added to the two 30,000 lb Stockless anchors to hold the anchor barge in position while the 9,000 lb mooring anchor tests continued. Subsequently, the 9,000 lb STATO anchor was used to assist the two 30,000 lb Stockless anchors while testing the 12,000 lb STATO anchor.

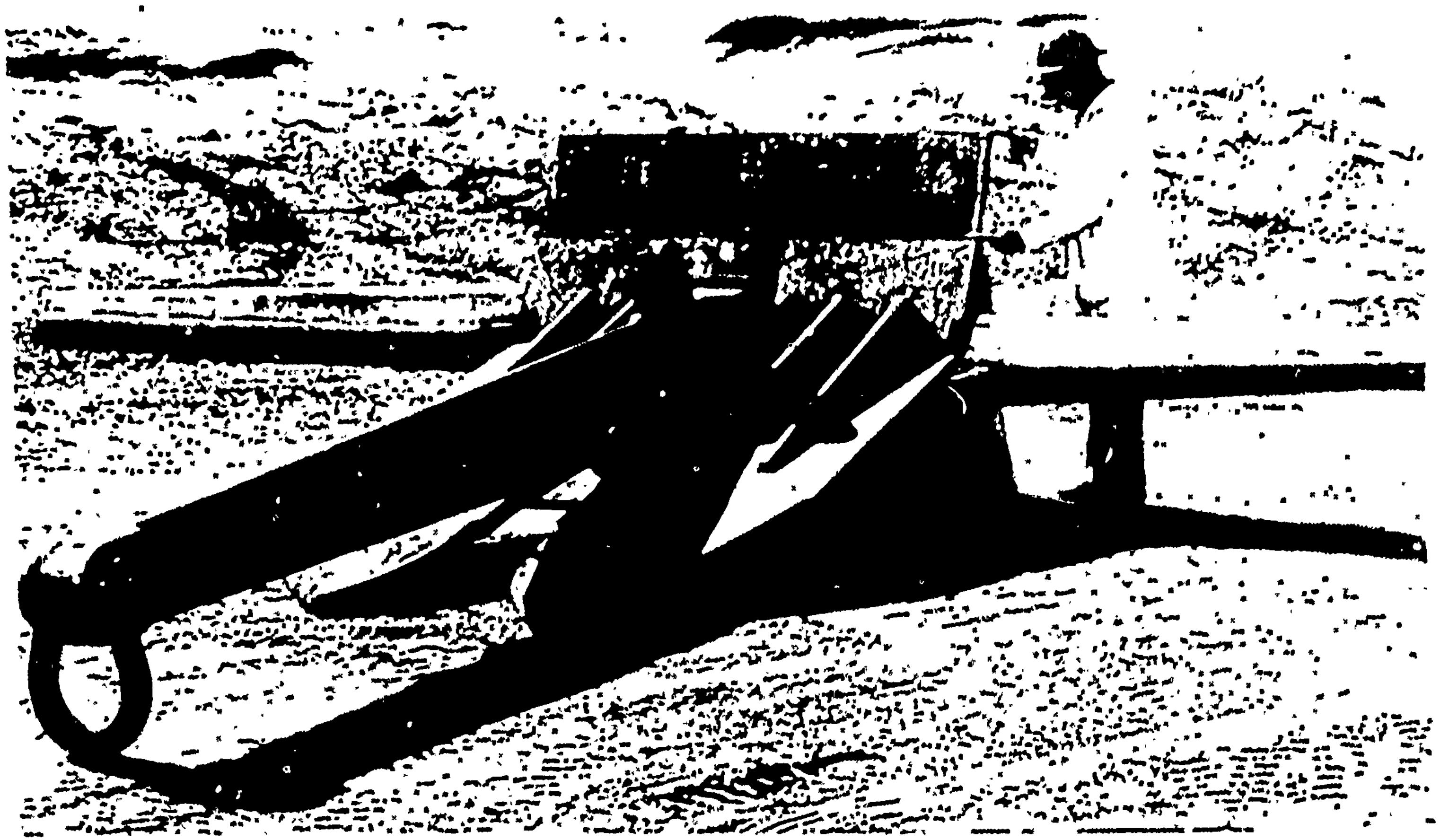


Figure 27. Technician indicating the palm extensions installed on 12,000-lb STATO mooring anchor for mud bottom operation.

Table VI lists, (1) ~~the average~~ holding powers of each anchor that were determined during the six test pulls (the averages are based on six test pulls), (2) the holding power to anchor weight ratio, and (3) the depth of burial into the mud, (4) the proof load and, (5) the average vertical force required to break the anchors loose from the mud bottom at the end of the test pull. Graphs showing the test results of the average of the six test pulls for each anchor are in Figures 28 through 32. The holding powers of the anchors at 0 degree chain angle, were:

Anchor Weight - lb	200	3000	6000	9000	12000
50 ft Drag Distance - kips	5.1	57.5	79.7	154.4	185.5
At Breakout Point Distance - kips	5.1	86.4	139.6	231.3	286.3

In every test, all five STATO anchors tripped and buried into the mud. In no instance did the anchor skid along the mud surface or rotate after seating into the bottom.

During the breakout tests on the 12,000 lb STATO anchor it was not possible to obtain the maximum breakout forcedue to structural limitations of the warping tug. Therefore the maximum breakout force measured was limited to 150 kips, however actual breakout force if measured would exceed this load during a continuous pull on the anchor.

The importance of the angle of the palm extensions (or tripping palms) in relation to the fluke was emphasized by a test in which the palm extensions were set at a 90 degree angle to the fluke instead of the previous 130 degree angle. It had been suggested that the 90 degree angle being perpendicular to the line of pull would tend to trip the flukes quicker. The palm extensions on the 3,000 lb anchor were modified to the 90 degree angle and the anchor was pulled six times at each chain angle of 0-, 6-, and 12-degrees. Table VI shows that the average holding powers at these chain angles after 50 ft drag were 27.1 kips, 29.0 kips and 24.1 kips respectively. Compare this to the holding powers of 57.5 kips, 50.1 kips, and 39.1 kips when the palm extensions are set at 130 degree angle to the flukes.

Table VI. Holding Power Data of BuDocks STATO Mooring Anchors In Mud Bottom

Anchor Weight lbs	Proof Load lbs	Average Holding Power - kips, length of drag: 50 ft	100 ft	150 ft	200 ft	250 ft	Chain Angle Degrees	HP/wt ratio	Avg Break-out Force-kips	Depth of Imbedment ft: 50 ft	End
200	9,000	5.1	5.6	4.6	4.2	5.1	0	21.3	—	—	8.6
200		6.4	6.2	5.1	4.8	5.3	6	26.7	—	—	—
200		4.9	3.8	4.3	3.9	4.4	12	20.4	—	—	—
3,000	90,000	57.5	83.3	87.7	87.4	86.4	0	17.3	53.3	17.6	24.8
3,000		50.1	59.2	63.5	66.2	68.1	6	13.0	37.0	—	17.9
3,000		39.1	57.1	54.2	54.9	61.4	12	10.6	35.0	—	8.9
3,000*	90,000	27.1	31.8	36.8	43.6	46.1	0	7.0	32.0	—	—
3,000*		29.0	42.0	44.8	45.1	46.7	6	7.4	34.8	—	—
3,000*		24.1	35.7	38.8	39.4	40.7	12	6.2	33.3	—	—
6,000	180,000	79.7	102.1	117.3	130.5	139.6	0	13.0	81.2	18.0	29.6
6,000		53.3	76.3	90.8	106.0	115.6	6	8.6	69.5	—	19.0
6,000		69.9	95.5	101.6	104.9	108.5	12	11.3	69.0	—	19.5
9,000	270,000	154.4	183.7	206.9	220.4	230.1	0	16.5	135.1	20.0	32.7
9,000		113.9	156.5	161.1	167.0	171.1	6	10.5	129.3	—	20.8
9,000		107.8	140.2	147.4	149.9	151.1	12	10.0	115.2	—	15.4
12,000	315,000	185.5	218.7	260.8	279.6	286.3	0	15.1	150.0	21.4	30.8
12,000		151.2	203.4	229.0	242.8	246.5	6	11.3	150.0	—	26.8
12,000		105.3	143.1	157.3	168.9	168.3	12	8.5	120.3	—	14.4

* Anchor equipped with palm extensions set at 90-degrees angle to flukes.

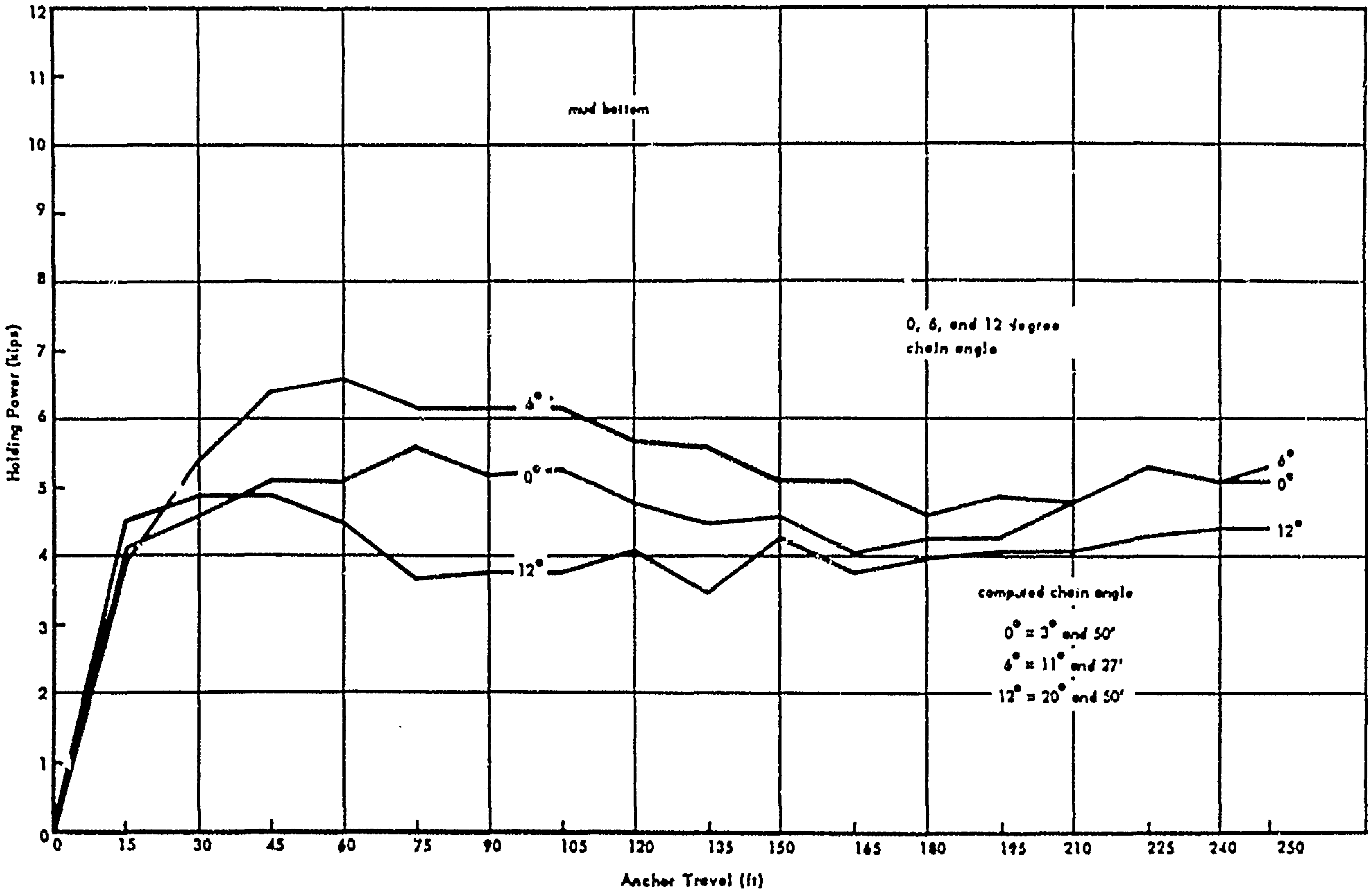


Figure 28. Graph of average test pulls on 200-lb STATO mooring anchor.

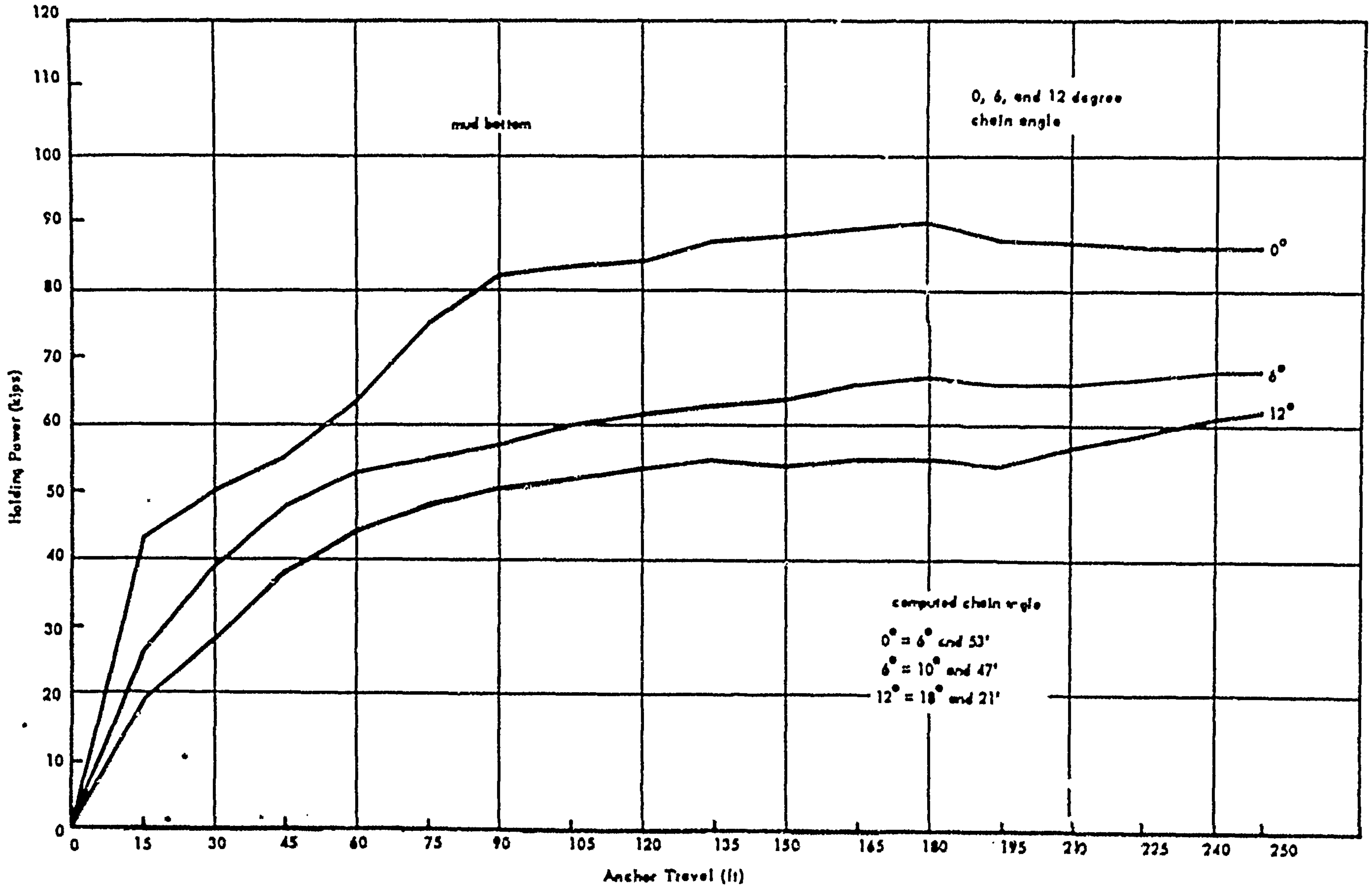


Figure 29. Graph of average test pulls on 3000-lb STATO mooring anchor.

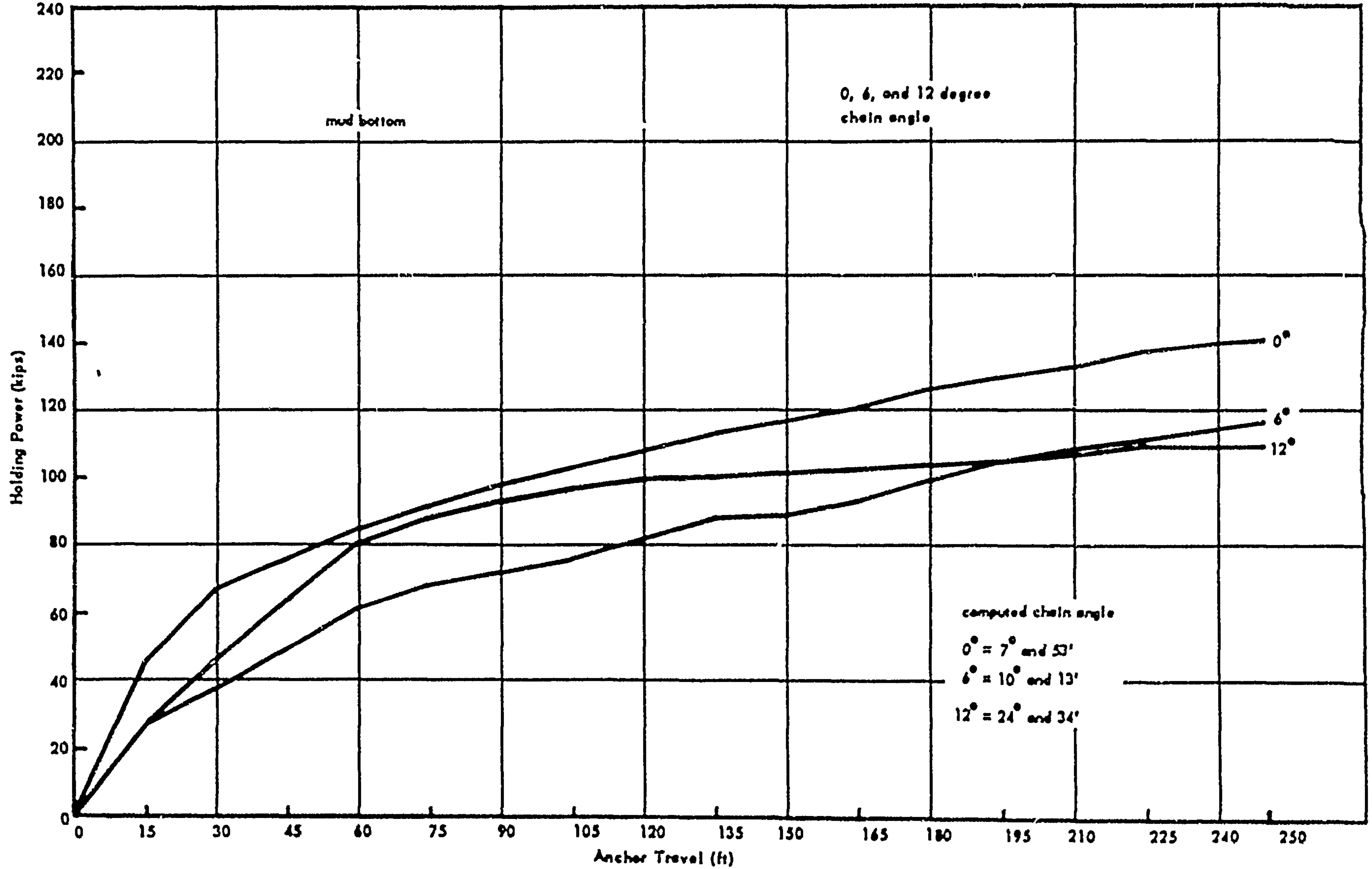


Figure 30. Graph of average test pulls on 6000-lb STATO mooring anchor.

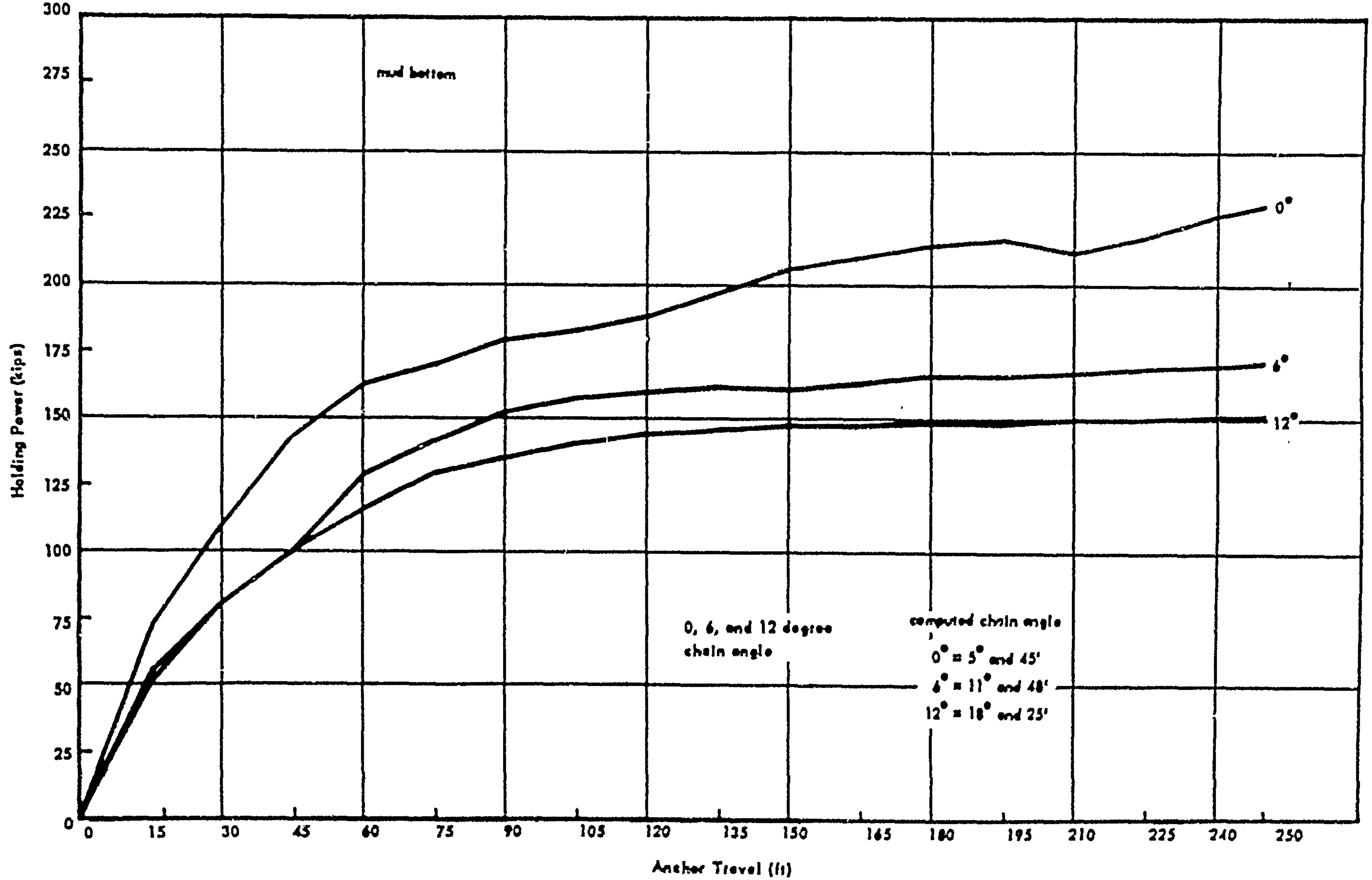


Figure 31. Graph of average test pulls on 9000-lb STATO mooring anchor.

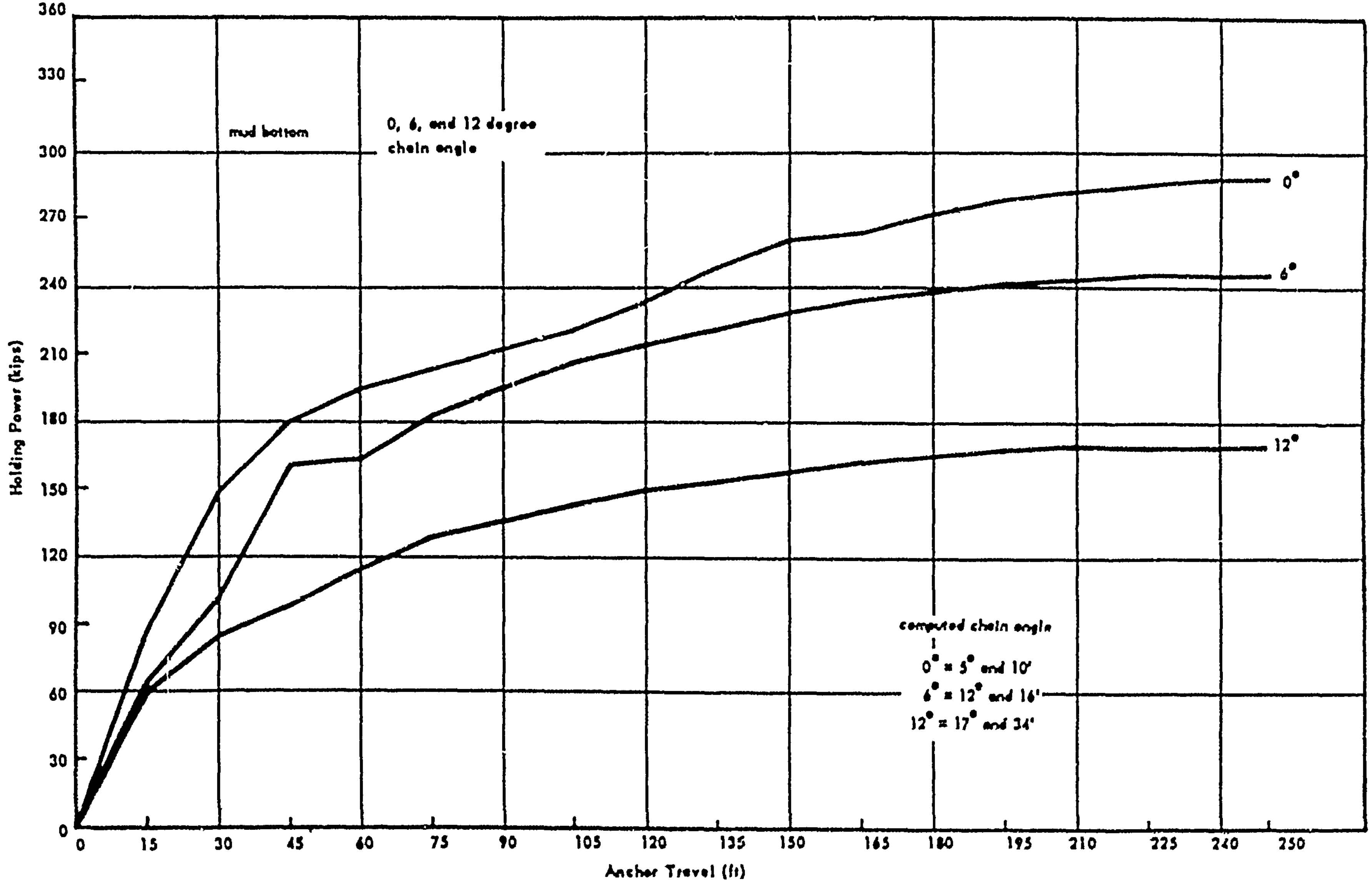


Figure 32. Graph of average test pulls on 12000-lb STATO mooring anchor.

ANCHOR CHAIN TESTS - MUD

The anchor chains alone were test pulled to determine their resistance when dragged through the mud bottom. The average holding power after 50-ft drag of 440 ft and 490 ft of 2-3/4 in. anchor chain was 12.0 and 15.8 kips, respectively.

DISCUSSION

The term mooring anchor, as used in this report, is an anchor which, in permanent moorings, provides a firm hold on the bottom for the attachment of riser chains to secure a buoy. Single fixed fluke mooring anchors bite quickly into the bottom but must be lowered into position so that the anchor lands in the proper position to the bottom. The hinged or moveable fluke type mooring anchor does not require lowering to the bottom but may be dropped or skidded from the deck of a vessel.

The bower or ships (stockless) anchor has been used in moorings without modification but it is inefficient and unsuitable for this purpose because of its instability and low HP/wt ratio. Compared to the stockless anchor, the mooring anchors described in this report, are more efficient in both sand and mud bottoms (see Table VII) and are more stable because of the addition of the stabilizer.

A fixed fluke anchor, such as an admiralty type, has the advantage of setting or biting into the bottom in a shorter distance than a movable fluke anchor. The fixed fluke anchor will normally develop approximately 80 percent of its maximum holding power after 20-ft of drag, while in this same distance the movable fluke anchor will develop only approximately 50 percent of its maximum holding power. However, for anchors of equal weight, the holding powers of an efficient movable fluke anchor will equal or surpass that of a fixed fluke anchor in a drag of 20 ft. This was substantiated by tests on several fixed fluke anchors[1].

The five STATO anchors, designed and tested by the Laboratory meet all of the design requirements specified. It must be remembered, however, that the holding powers recorded during the tests were for the specific soil conditions encountered at the test sites and that anchor holding power varies with soil composition and stratification.

The holding power to anchor weight ratio, 20 to 1, for the STATO anchors appears relatively small when compared with claims of 80 to 1 or 250 to 1 for certain weight Kite and Danforth type anchors, but it is not possible to compare

Table VII. Holding Power Data of Stockless, Lightweight and Danforth Anchors

Anchor Type	Anchor Weight lbs	"Fluke angle" degrees	Average Holding Power (Sand) kips length of drag			Chain angle degree	Average Holding Power (Mud) kips length of drag			Break-out Force (kips)	
			50 ft	100 ft	150 ft		50 ft	100 ft	150 ft	Sand	Mud
Standard	6,000	35	35.3	50.1	54.0	0	17.1	19.4	22.4	23.0	14.0
Standard	6,000	35	33.0	35.7	34.0	6	14.9	15.8	17.5	20.6	—
Standard	6,000	35	20.3	22.7	25.3	12	8.7	10.9	11.9	19.4	—
Standard	10,000	47	53.8	64.3	70.3	0	24.2	28.0	30.8	44.6	—
Standard	10,000	47	46.3	49.0	49.0	6	24.2	26.3	27.1	35.3	—
Standard	10,000	47	27.3	32.0	34.0	12	17.0	17.1	19.2	33.8	—
Standard	30,000	34	133.2	196.4	237.0	0	61.0	78.1	93.7	70.9	57.3
Standard	30,000	34	93.7	122.5	135.2	6	53.1	64.1	70.4	77.4	47.4
Standard	30,000	34	81.0	98.0	111.6	12	61.9	82.7	90.2	104.1	54.5
Lightweight	3,000	30				0	11.7	12.6	12.9		8.9
Lightweight	3,000	30				6	10.0	12.6	13.0		7.5
Lightweight	3,000	30				12	8.4	10.2	11.1		8.3
Lightweight	10,000	30				0	18.8	20.9	21.1		12.7
Danforth	2,770	34	52.5	63.3	65.3	0	27.8	31.2	36.0	14.0	15.8
Danforth	2,770	34	51.2	70.0	78.0	6	22.6	25.8	29.4	24.6	—
Danforth	2,770	34	49.0	57.0	61.2	12	19.4	24.3	24.6	25.6	—
Danforth	10,000	34	106.3	119.0	124.2	0	30.6	36.2	37.7	74.5	27.0
Danforth	10,000	34	72.2	102.2	101.5	6	28.8	31.5	34.6	86.5	36.0
Danforth	10,000	34	64.0	73.0	76.6	12	25.2	27.9	29.8	76.6	28.5

these anchors with the STATO anchors because the length of drag, speed of drag, soil characteristics, water content, number of tests, size of chain etc. required to produce these holding powers is not known. Small increases in the speed of drag can result in large indicated holding powers. Both the Kite and Danforth anchor types have the basic characteristics necessary to produce large holding powers: large fluke areas (2592 sq. in. for 1500 lb Kite anchor), fabrication from steel plate, no large crown to present resistance to burial, and approximately 50 degree fluke angle for optimum operations in mud (Kite anchor). Their disadvantage is a fixed fluke angle (in the Kite anchors and in some Danforth anchors) which normally requires setting the anchors in an upright position, and prohibits optimum operation in both mud and sand bottoms.

By using high tensile steel and increasing the length of drag, the final holding powers of the STATO anchors could be increased to 20,000 lb, 110,000 lb, 200,000 lb, 340,000 lb, and 360,000 lb (extrapolated values of the curves in Figures 15 through 19.) This increase in holding powers persists for all sizes of STATO anchors rather than only certain weights of the anchors. Again it should be noted that these holding powers are for the type of sand present at the test sites and for the speed of drag used during the tests. While, of the commercial anchors previously test,[1,2,3] a specific anchor may have shown a greater holding-power to anchor-weight ratio in a specific soil condition, no anchor tested by the Laboratory has consistently equaled the performance of STATO anchors in either sand or mud bottoms. From the many tests conducted by the Laboratory and others[8] on various types of anchors, it has been noted that the Danforth type anchor produced results nearly comparable to the STATO anchors.

The principal new design features developed which produce the more efficient operation of the STATO mooring anchor, are the wedge insert for field adjustment of the fluke angle and the palm extensions which assure tripping of the anchor flukes in mud.

The 0-, 6-, and 12-degree chain angles used to test each of the STATO anchors were computed on the basis of the expected holding power of 20 to 1 at the 50 ft drag point. Results of the tests[1] on Navy Stockless anchors indicated that their holding power in sand bottom decreased by approximately 15 percent at 6-degree chain angle and by approximately 38 percent at a 12-degree chain angle. The computed chain angle closely approximated the actual chain angle during the stockless anchor tests because of the small amount of anchor burial. Thus variations in soil conditions and increased holding power at greater depths are not introduced in the computation, and variance in the chain angle is primarily controlled by changing the length of the chain. The STATO anchor is

designed to bury itself deeply into the ocean bottom, and the additional depth of burial and resulting increase in holding power have a marked effect on the chain angle. Consequently, the original computed values for the various chain angles used in the STATO anchors tests varied from the actual values. The chain angles shown on the graphs in Figures 15 through 19, Figures 28 through 32 and Appendix E are computed values based on estimated holding power and no anchor burial. The actual chain angle values, computed on the basis of the measured holding powers and measured anchor burial, are shown at the bottom of each of the graphs.

Results of the tests of the STATO anchors, at computed chain angles of 0-, 6-, and 12-degrees, indicate that either the holding powers were unaffected by the shorter chain lengths (Figure 17) or that the holding powers were not effected uniformly by the shorter chain lengths (Figure 18). The computed values of the chain angles for the tests in Figures 17 and 18 show that the chain angles in each test varied in accordance with the chain length, holding power, and depth of burial. Applying the Farrin and Leahy theory[9] shows that the holding power depends directly upon the fluke area moment: the chain angle assumes the specified direction of pull on the anchor shank and as the anchor buries and travels through the bottom, it rotates longitudinally because of the up lift on the shank caused by the shortened chain length; this rotation reduces the project fluke area and in effect reduces the holding power. Consequently, anchors with small fluke angles and deep burial characteristics will be sensitive to changes in the attitude of the anchor in relation to the bottom. The STATO anchors tend to continue to bury themselves during dragging and eventually assume an attitude of equilibrium dependent upon the length of drag.

During several of the tests of the STATO anchors at a 6-degree chain angle, the anchors buried themselves rapidly and reached a maximum (proof load) holding power (Figures 15, 16, and 17) before the anchor could be affected by the chain which was pulling at approximately the 6-degree angle. During the mud bottom tests, the anchors were more readily affected by the chain angle because the soil was more fluid; a more uniform change in holding power at 0-, 6-, and 12-degrees was recorded (Figures 28 through 32). Stockless anchors have initial fluke angles of 45 degrees and even after the anchors have rotated because of the change in chain angle, still have a relatively large projected fluke area. The computed holding powers of the STATO anchors at 0-, 6-, and 12-degree chain angles are based on the variations of the measured holding powers at different chain angles and are listed in Table VIII. For the "family" of anchors the average decrease in sand bottom holding power is 19 percent at 6-degree chain angle and 40 percent at 12-degree chain angle. Chain lengths could not be easily changed during the tests to adjust for variations in the tide and therefore the computed effect of tide change on the chain angle was found to range ± 1.5 degrees.

Table VIII. Computed Anchor Holding Power

Anchor Weight lb	*Holding Power - lb Sand Bottom			*Holding Power - lb Mud Bottom		
	Chain Angle-Degrees			Chain Angle-Degrees		
	0	6	12	0	6	12
200	11,000	8,600	5,600	5,700	4,500	2,800
3,000	7,400	61,000	48,000	60,000	50,000	40,000
6,000	123,000	93,000	63,000	79,000	66,000	56,000
9,000	200,000	164,000	128,000	154,000	109,000	89,000
12,000	236,000	194,000	152,000	194,000	151,000	96,000

* At 50 ft drag

The holding powers of the anchors are in accord with the theory, expressed by Leahy and Farrin[9], that the holding power is a function of the moment of the project fluke area about a ground surface. While the holding power may be stated as proportional to the projected fluke area moment, it might be more specifically identified as a function of the soil density and anchor size (shape) which in turn is dependent upon the depth. Graphs of holding power versus fluke area moment for the STATO mooring anchors in sand and mud bottoms are shown in Figures 33 and 34. Several Navy anchors, with and without stabilizers, and Danforth anchors are included in the graphs for comparative purposes. A convenient method of expressing the holding power of an anchor is by stating it as a ratio to the anchor weight in air, since the weight is a commonly available value. The ratio of the holding power (at the 50 ft drag point with a 0-degree chain angle) to anchor weight in air for the STATO anchors is 20/1 for sand and 15/1 for mud: $HP/W_a = 20$ in sand and $HP/W_a = 15$ in mud.

Expressing the holding power of the anchors as the average of the six test pulls may be supplemented by considering the holding powers in terms of either the confidence limits of the holding power values obtained or as a confidence interval expressed at a confidence level. With the variations in holding powers present due to inherent variables in soil conditions, the reliability of expressed holding powers may perhaps be best stated at a confidence level of 95 percent. This means that the expressed holding power interval or limits will be wrong in 5 percent of such statements. Higher confidence levels may be used, however the limits become so far apart that they are unusable in this study. Therefore, the expressions of the confidence limits of the holding powers of the mooring anchors in Table IX and Appendix D are based on a 95 percent confidence level. It is believed this information will provide the designer of a permanent mooring with a little better conception of the reliability of the expressed holding powers and some additional basis for designing the safety factor in a mooring. The confidence limits of the holding powers at a 95 percent confidence level for the STATO mooring anchors in sand bottom follow.

Anchor Weight (Pounds)	Confidence Limits 95% (Pounds)
200	7,000 - 12,000
3,000	55,000 - 83,000
6,000	117,000 - 129,000
9,000	189,000 - 210,000
12,000	241,000 - 250,000

Graphs which show the variations between the six test pulls appear in Appendix E.

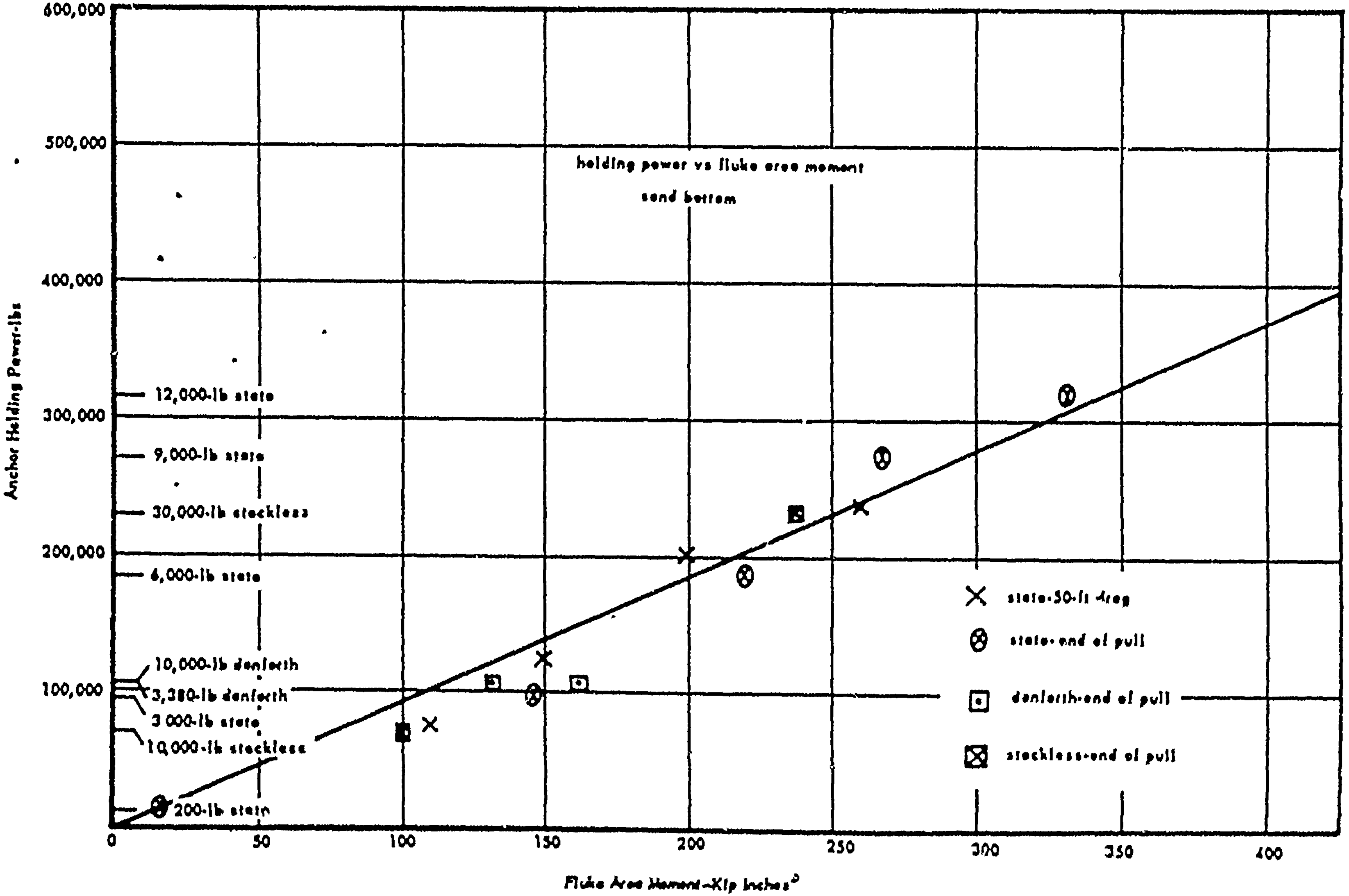


Figure 33. Graph of holding power vs fluke area moment – sand bottom.

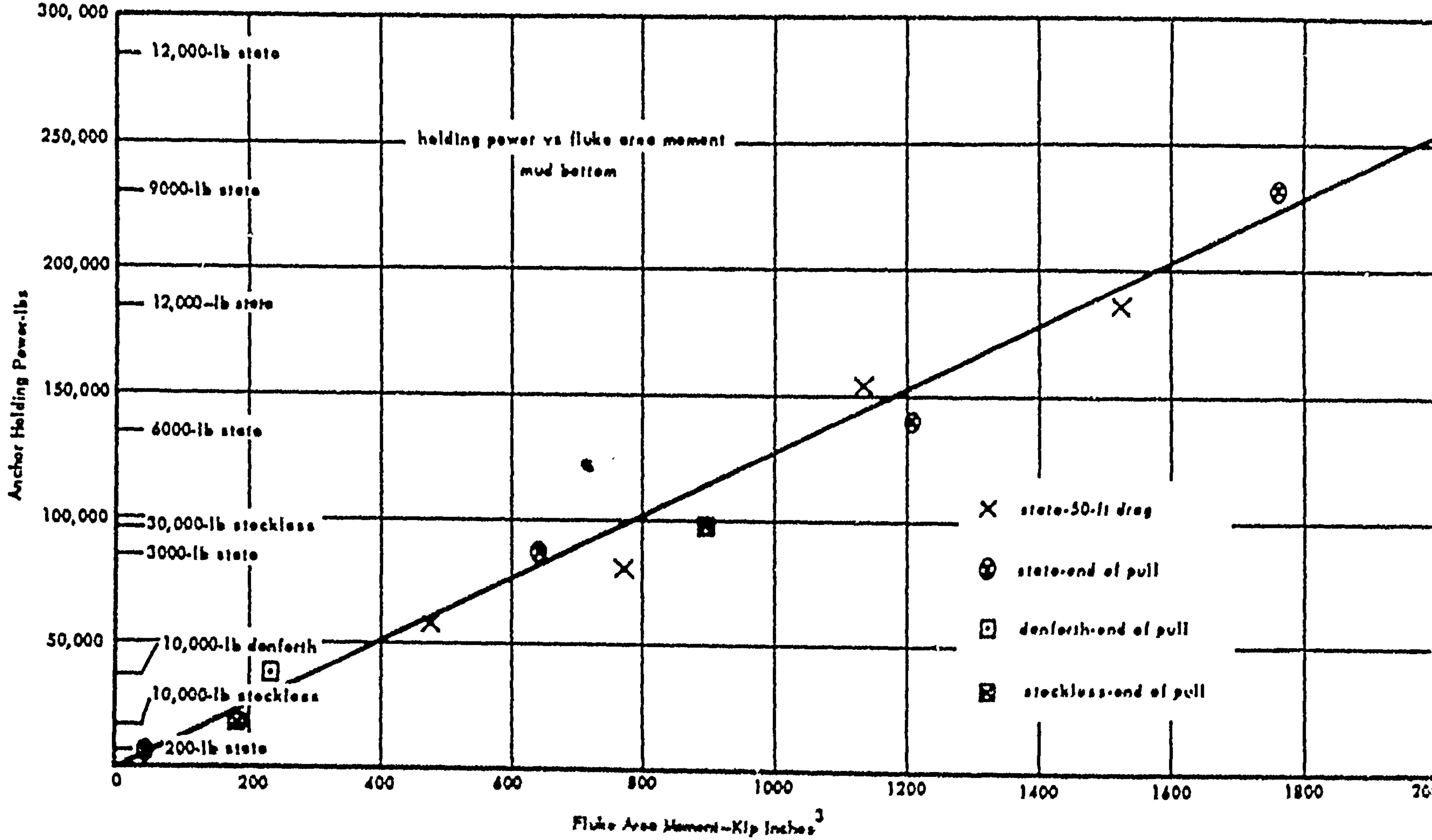


Figure 34. Graph of holding power vs fluke area moment – mud bottom.

Table IX. Confidence Limits for Holding Power of BuDocks STATO Mooring Anchors

Anchor Weight lb	Avg HP* 50 ft kips	Deviation Squared	Variance	Std. Dev.	Variance of Average	Confidence Limits 95% confid. level-kips	
						upper	lower
200 (sand)	9.6	28.9	5.7	2.4	.97	12.1	7.0
(mud)	5.1	9.9	1.9	1.4	.33	6.6	3.6
3000 (sand)	68.9	919.0	183.8	13.5	30.63	83.1	54.6
(mud)	54.1	629.3	125.8	11.2	20.98	65.8	42.3
6000 (sand)	122.8	151.6	30.3	5.5	5.05	128.6	117.0
(mud)	79.7	423.6	84.7	9.2	14.12	89.3	70.0
9000 (sand)	199.8	99.8	48.9	7.0	16.32	210.2	189.3
(mud)	154.4	1530.7	306.1	17.4	51.02	172.7	136.1
12000 (sand)	245.4	18.4	9.2	3.0	3.07	250.0	240.7
(mud)	185.5	2608.6	521.7	22.8	86.95	209.4	161.5

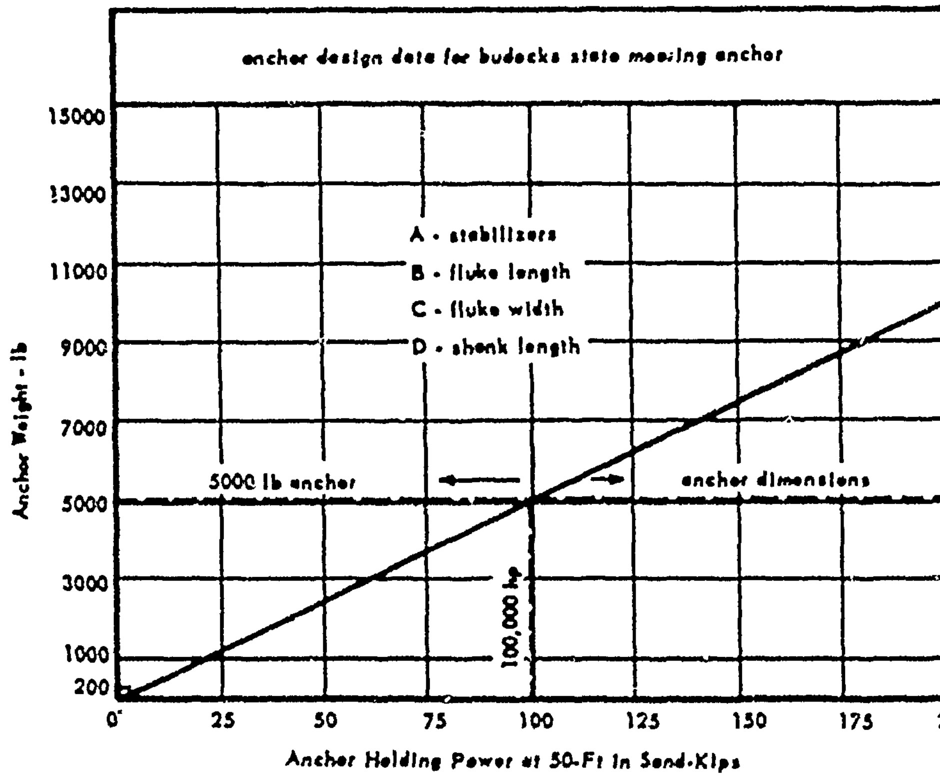
* HP = Holding Power

The measured breakout force for the STATO anchors is relatively high when compared to anchors which do not bury deeply into the soil. The values listed in Table II are typical of the force necessary to retrieve the anchors by lifting on the anchor chain, but if a marker buoy with lifting line is attached to the anchor crown, then the breakout force will be less because when the lifting line is retrieved it will pull the anchor backwards.

To permit fabrication of anchor weights different from the "family" tested or to select a specific holding power (within relative confidence limits) a graph has been prepared plotting anchor weight versus holding power versus pertinent anchor dimensions (Figure 35). In this graph, one typical example has been shown in dash lines. If a holding power of 100,000 lb is desired (at the 50 ft drag point in a sand bottom), then the intersection of this holding power with the curve indicates that the desired anchor would weigh 5,000 lb and the dimensions of the principal parts are shown at the right to be: stabilizers 40.7 in., fluke length 77.6 in., fluke width 22.0 in., and shank length 139.0 inches. It must be remembered that this is a particular "family tree" anchor and expected performance will be subject to soil conditions. The depth of burial in sand, similar to test area soil, would probably average approximately 4.2 ft (ground surface to top of shank).

K. P. Farrell shows[7] that some methods of proof loading anchors by using spacers between the shank and flukes, penalizes anchors which work at low fluke angles. The U. S. Navy method uses no spacers, and loads through holes in the flukes. This appears to be the most satisfactory method of applying the load, however, fluke-yokes which use neither holes nor spacers were adapted for proof loading the STATO mooring anchors. Figure 36 is a graph showing the proof loads and holding powers for the "family" of anchors.

In order to obtain some indication of commercial manufacturing costs and fabrication problems a small shop was engaged by contract to make the 3,000 lb mooring anchor. The cost for the one anchor with wedge insert and palm extensions was $1,648.00 or $0.55/lb. No fabrication problems were encountered. The anchors fabricated in the Laboratory shops, using government purchased material, cost approximately $0.25/lb.



ANCHOR DIMENSIONS INCHES			
A	B	C	D
74.0	121.0	33.0	205.0
70.0	115.8	31.8	197.4
66.0	110.6	30.6	189.8
62.0	105.6	29.4	180.0
58.0	100.8	28.2	170.4
54.0	96.0	27.0	160.0
50.0	90.4	25.8	153.6
46.0	84.8	24.6	147.2
42.0	79.4	22.8	141.0
38.0	74.2	20.4	135.0
34.0	69.0	18.0	129.0
30.6	59.8	16.3	110.4
23.8	41.4	12.9	73.1
18.0	26.0	10.0	42.0

Figure 35. Graph of anchor design data.

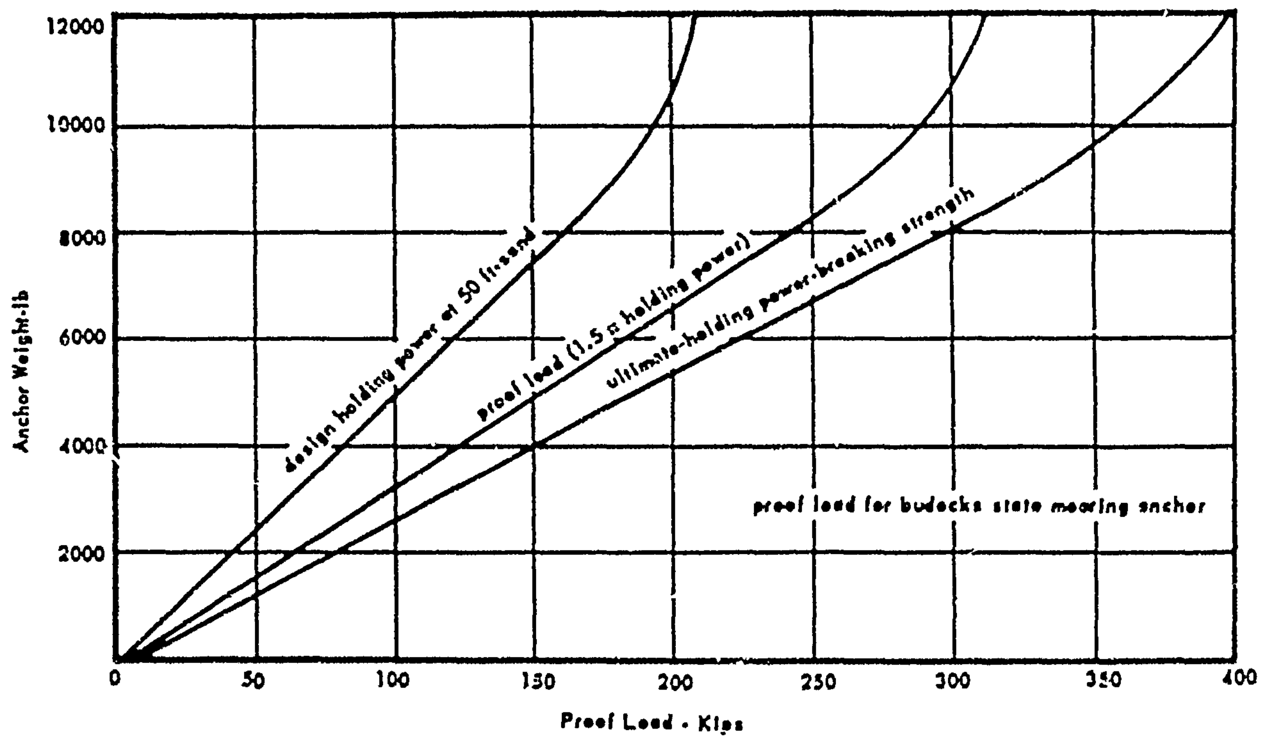


Figure 36. Graph of proof loads for STATO anchors.

CONCLUSIONS

The following conclusions are based on results of the tests conducted in the mud and sand bottoms described throughout this report:

1. The design of the BuDocks STATO mooring anchor fulfilled the holding power specifications. After 50-ft drag, the average holding power versus anchor weight in air ratios in sand and mud bottoms are approximately 20/1 and 15/1 respectively. This holding-power-to-anchor-weight ratio for the "family" of mooring anchors is good in sand bottoms when compared to other light-weight type anchors and is excellent when mud bottom holding powers are compared.

2. The wedge insert was found to be a practical and efficient method of reducing the fluke angle to 34-degrees for sand bottom operation.

3. The palm extensions require additional welding but did make the flukes trip in every instance in mud bottom operation. The extensions should be set in line with the tripping palms at an angle of 130-degrees to the flukes.

4. A 50-degree fluke angle is satisfactory in mud bottom.

5. Anchors of this design are sensitive to small dimensional variations and soil conditions.

6. The holding-power-to-anchor-weight ratio of the STATO mooring anchors is superior to the Navy stockless anchor, with or without stabilizers, in both mud and sand bottoms.

7. Fabricating the anchors from mild steel plate was accomplished but details required reduce the holding-power-to-anchor-weight ratio.

8. Breakout force of the STATO anchors is larger than for stockless anchors or other anchors which do not bury deeply into the ocean bottom.

RECOMMENDATIONS

It is recommended that the BuDocks STATO anchors be in-service tested in permanent type moorings to determine any adverse operational characteristics which may become apparent through varying or continuous operational usage.

ACKNOWLEDGMENTS

1. The Commanding Officer, San Francisco Naval Shipyard authorized the Laboratory to conduct tests at Hunters Point and with the excellent cooperation extended by the Public Works Officer the tests were completed with a minimum of delay and cost.

2. The Twelfth Naval District Public Works Office, San Bruno, California is to be commended for their excellent assistance in analyzing and providing graphs of the soil samples taken in San Francisco Bay.

3. Mr. R. S. Danforth of Berkeley, California, manufacturer of Danforth Anchors, supplied several new type anchors for comparative test purposes without cost to the government.

4. The Baldt Anchor Chain and Forge Division of the Boston Metals Company furnished two new mud anchors of their design and a Croseck anchor for test and observation without cost to the government.

REFERENCES

1. R. C. Towne, Test of Anchors for Moorings and Ground Tackle Design, NCEL Technical Memorandum M-066, 10 June 1953.

2. R. C. Towne and J. V. Stalcup, Tests of BuShips Anchors in Mud and Sand Bottom, NCEL Technical Note N-195, 5 August 1954.

3. R. C. Towne and J. V. Stalcup, Tests of Anchors for Moorings and Ground Tackle Design in Mud Bottom, NCEL Technical Memorandum M-097, 15 December 1954.

4. BuDocks letter to NCEL, Hr D-421B/EHL, 9 May 1958.

5. STATO - A combining form from Greek 'statos' meaning fixed; also the initial letters in the names (Stalcup, Towne) of the two NCEL employees who designed and developed the new mooring anchors.

6. H. L. Dove, "Investigations on Model Anchors," Transactions of the Institute of Naval Architects, XCII, 1950.

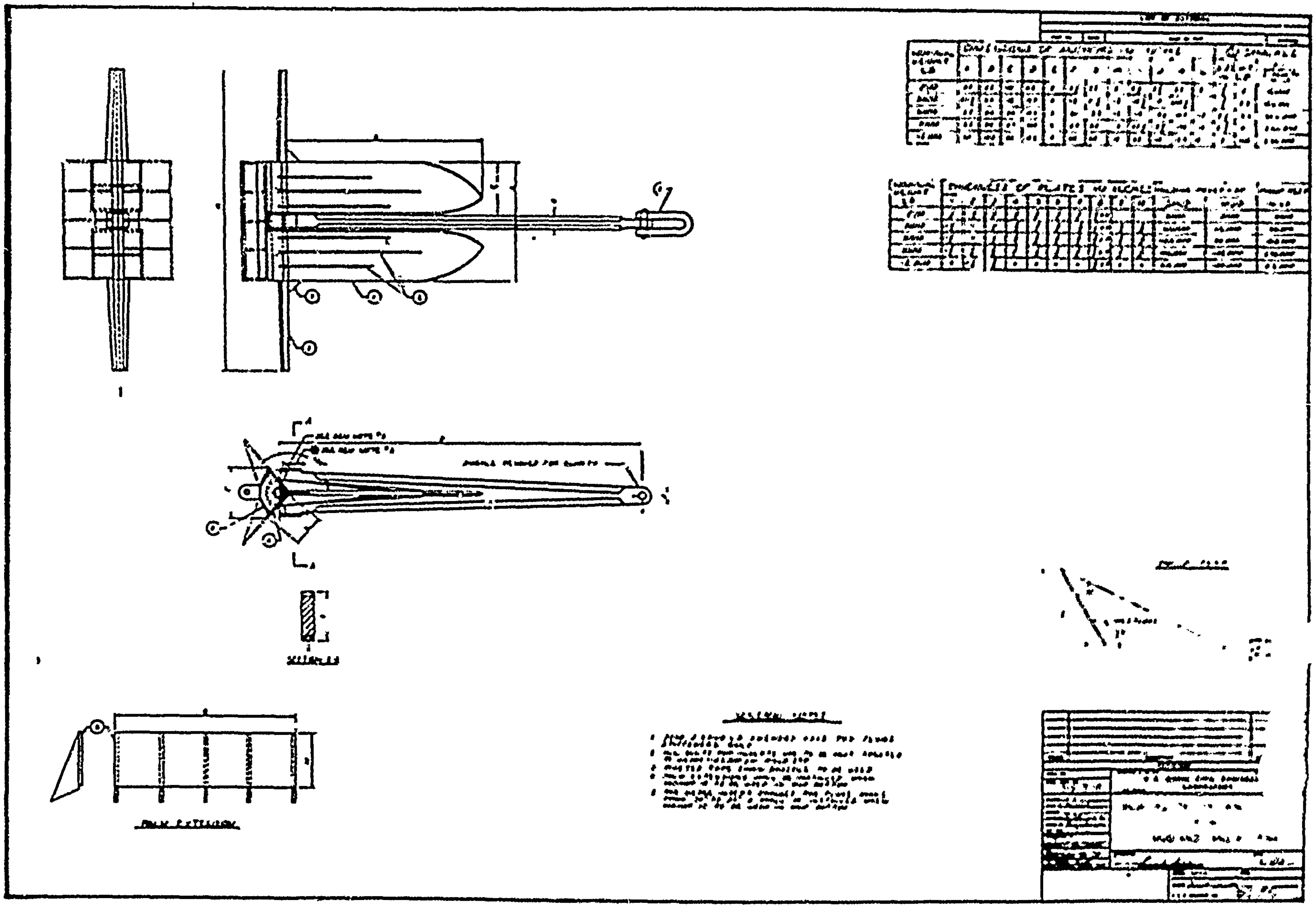
7. K. P. Farrell, "Improvements in Mooring Anchors," Transactions of the Institute of Naval Architects, XCII, 1950.

8. A. V. Nunez, "Experiments with Modern Types of Anchors," trans. Philip Chaplin, Ingenieria Naval, XIX No. 188, February 1951.

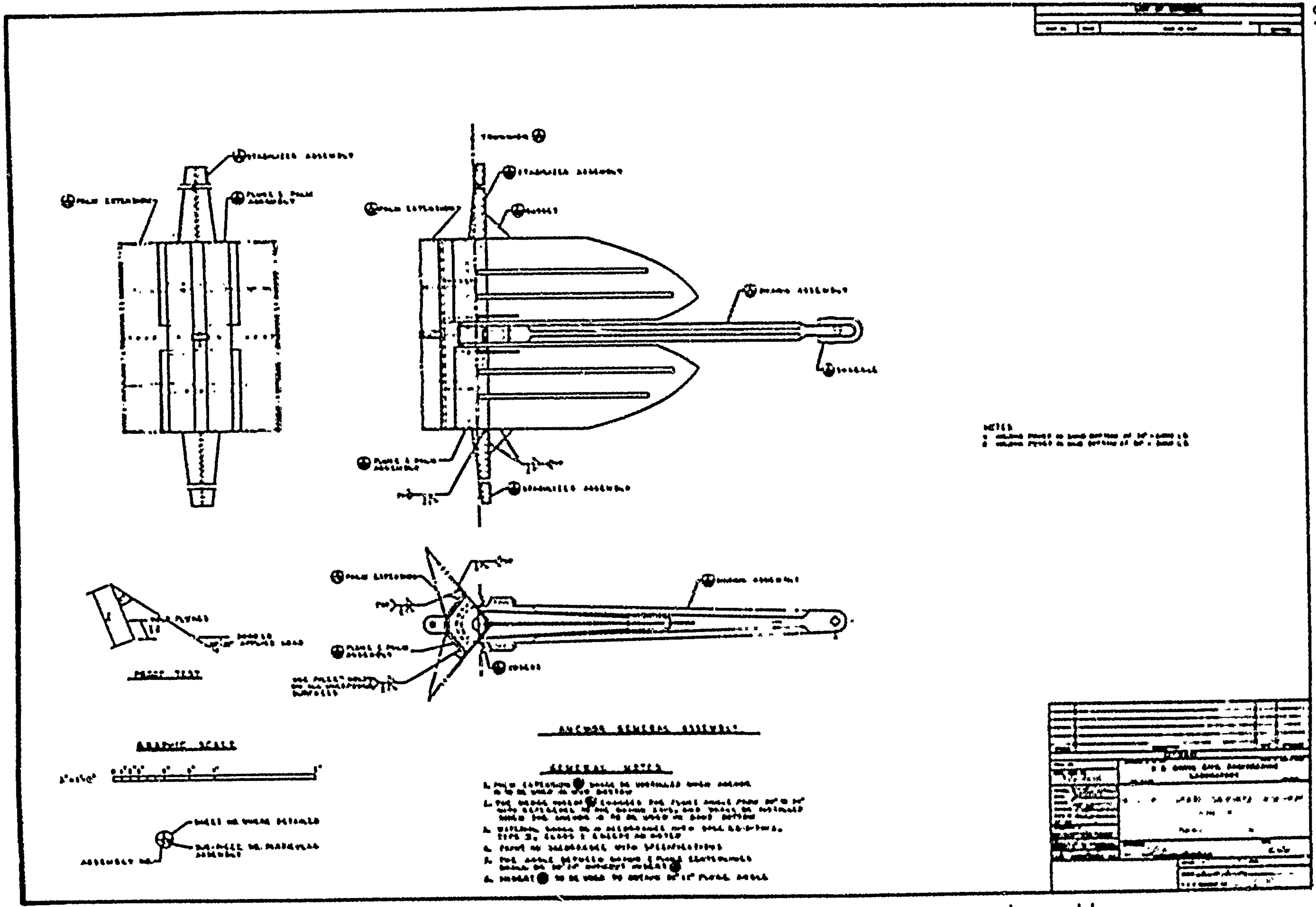
9. W. H. Leahy, Lt (CEC) USN, and H. H. Farrin, Lt (CEC) USN, "Determining Anchor Holding Power from Model Tests," Transactions of the Society of Naval Architects and Marine Engineers, XLIII, 1935.

APPENDIX A

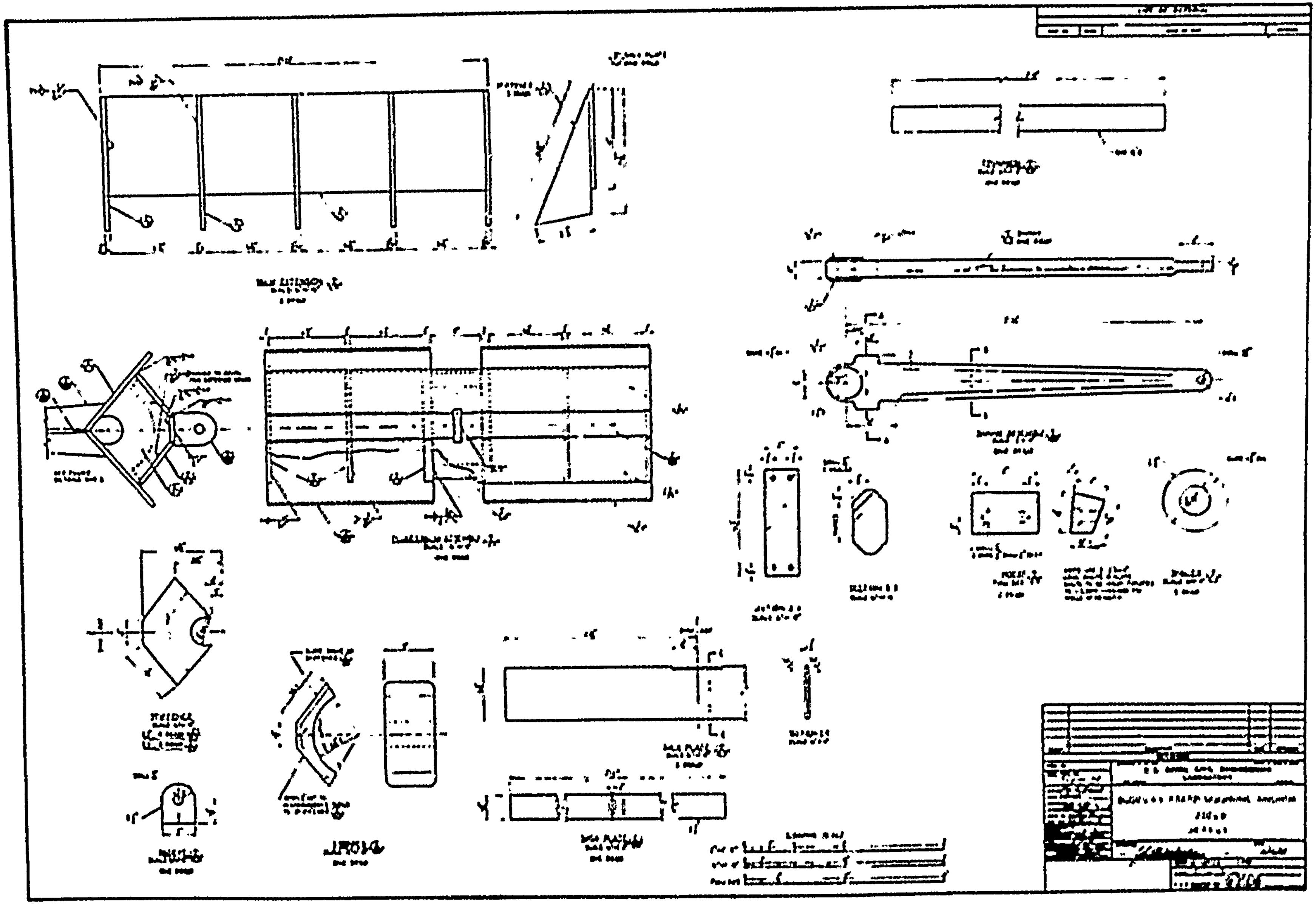
BUDOCKS STATO Mooring Anchor Yards and Docks
Drawings Nos. 813506 through 813521



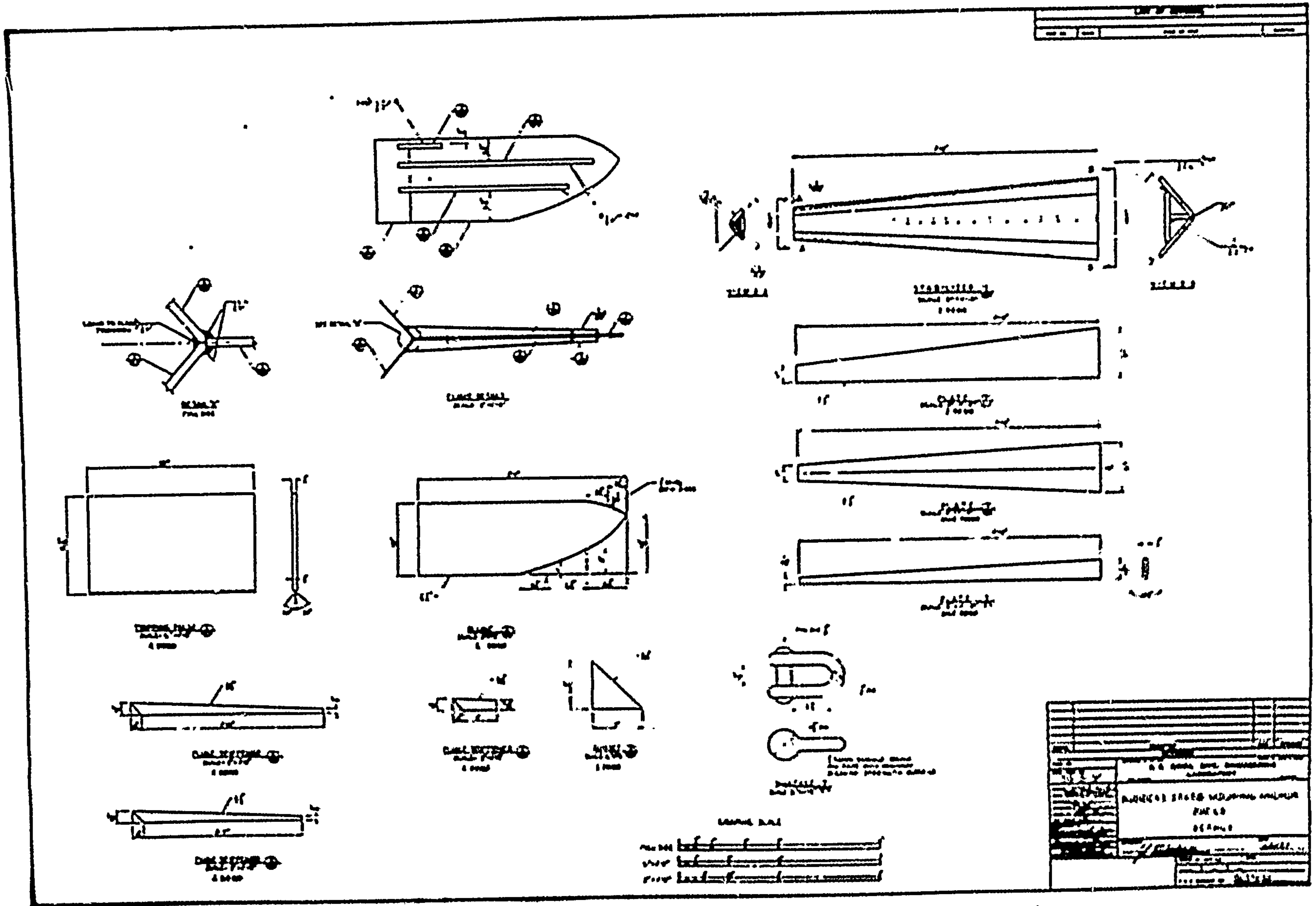
Y & D Drawing No. 813506 BUDOCKS STATO mooring anchor for mud and sand bottoms



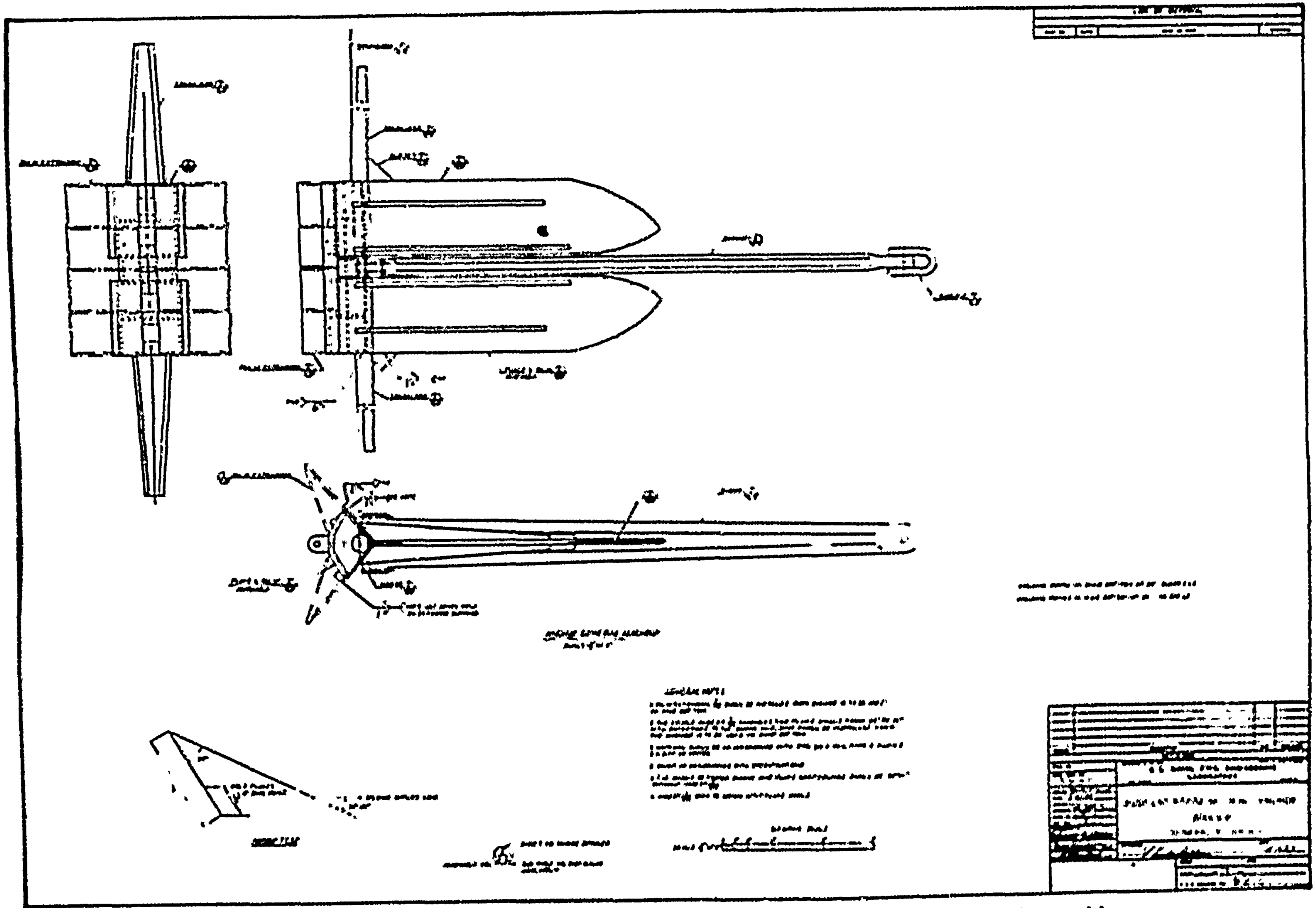
Y & D Drawing No. 813507 BUDOCKS STATO mooring anchor, 200 lb, general assembly



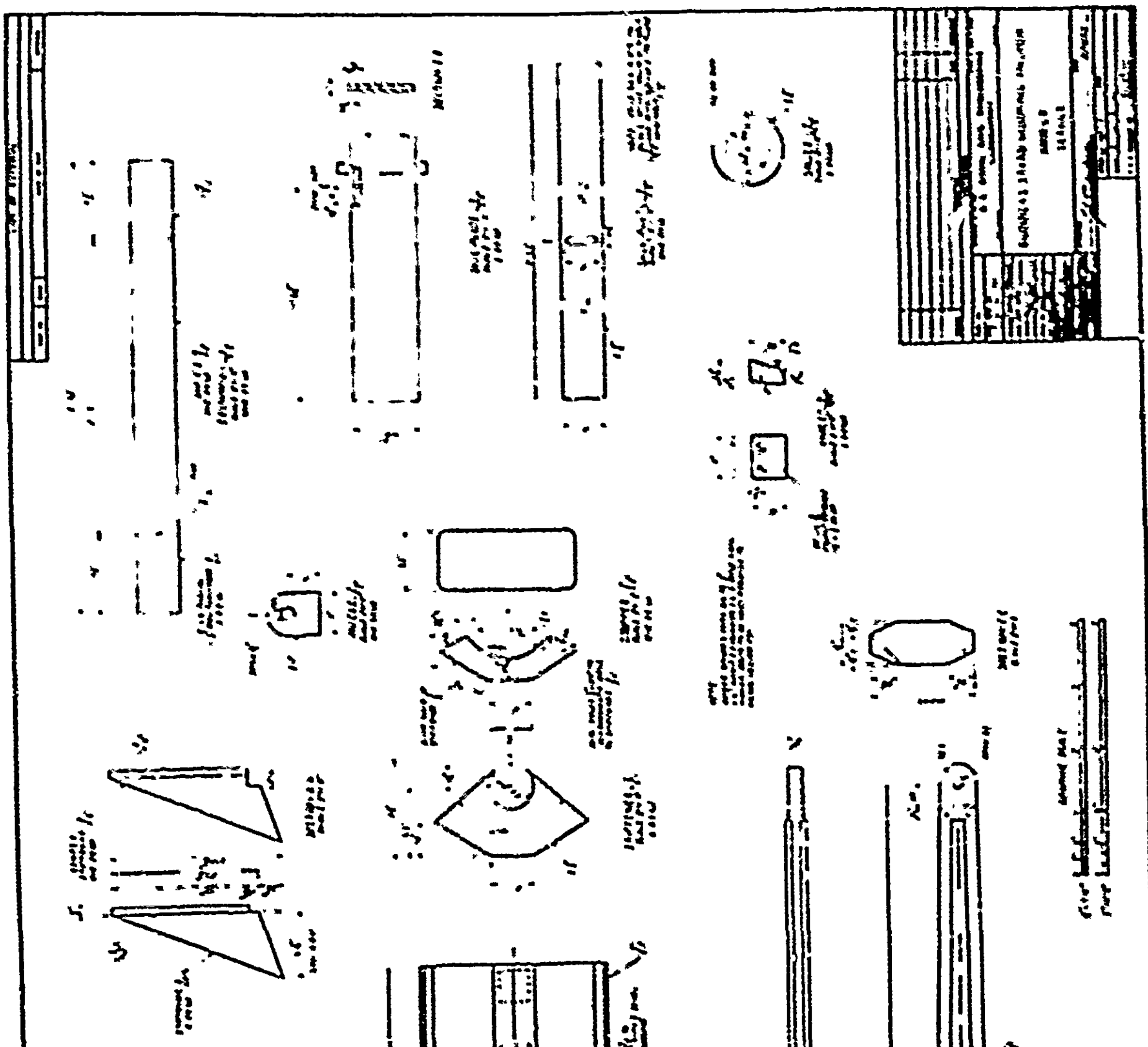
Y & D Drawing No. 813508 BUDOCKS STATO mooring anchor, 200 lb, details



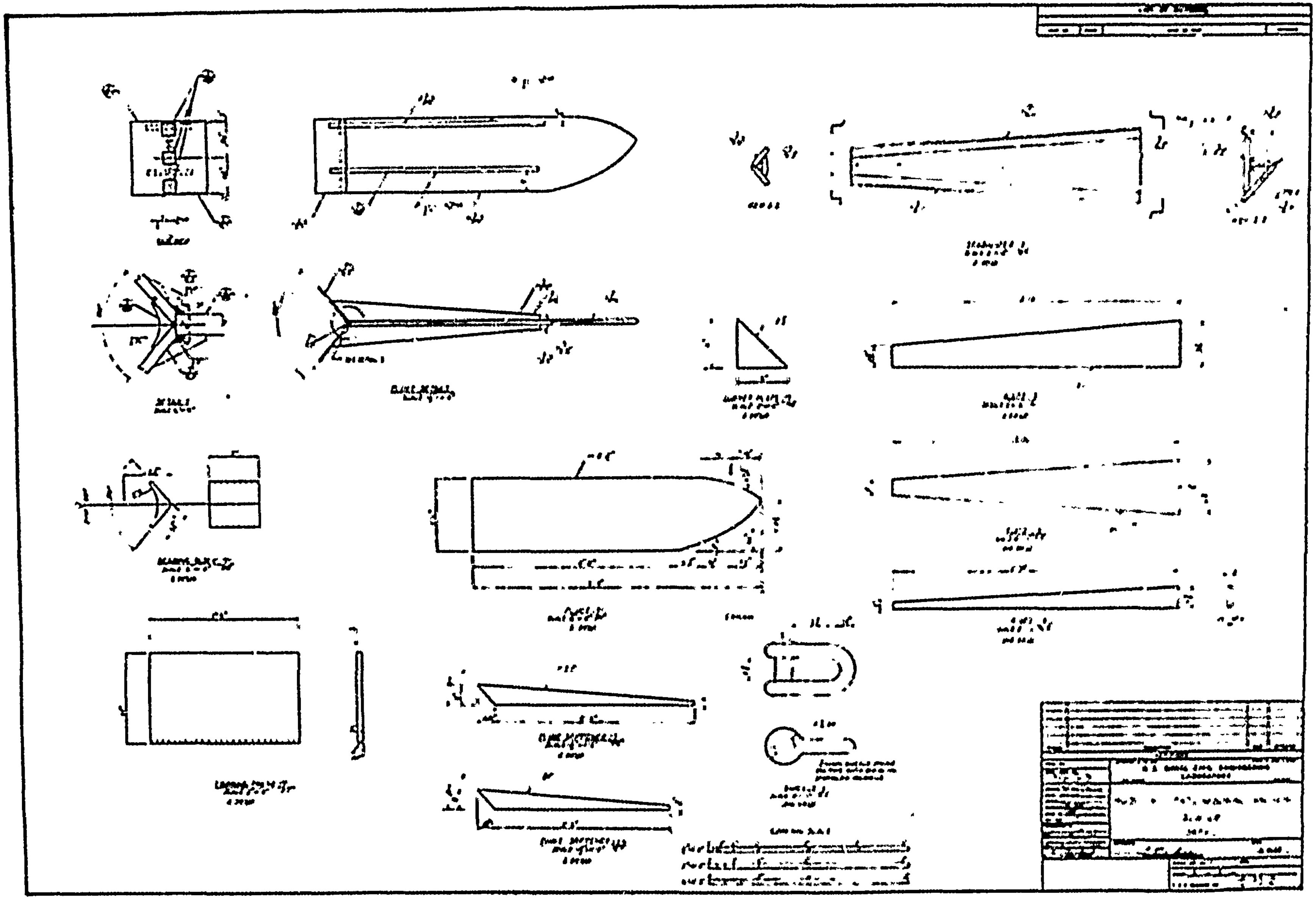
Y & D Drawing No. 813509 BUDOCKS STATO mooring anchor, 200 lb, details



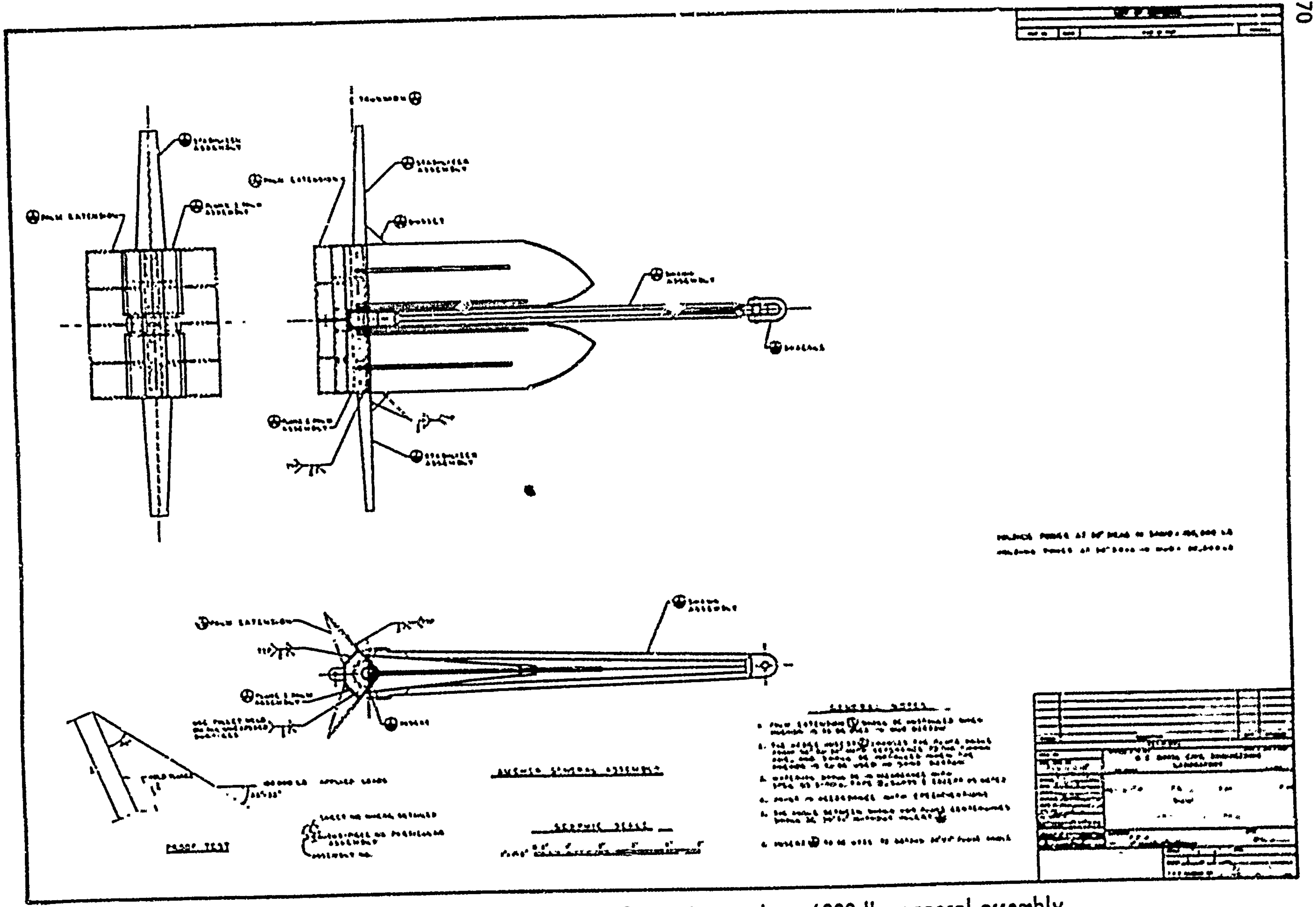
Y & D Drawing No. 813510 BUDOCKS STATO mooring anchor, 3000 lb, general assembly



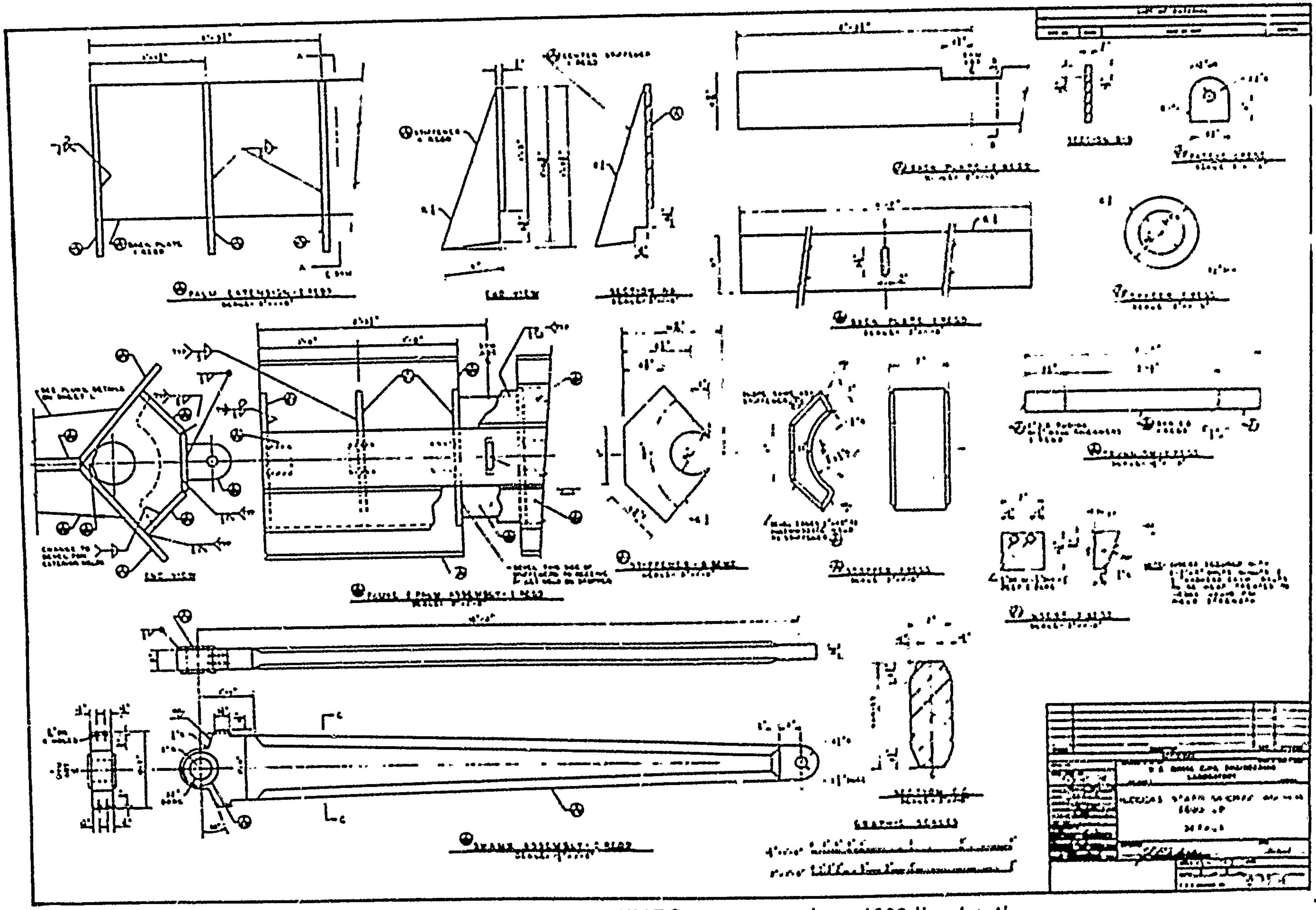
Y & D Drawing No. 813511 BUDOCKS STATO mooring anchor, 3000 lb, details



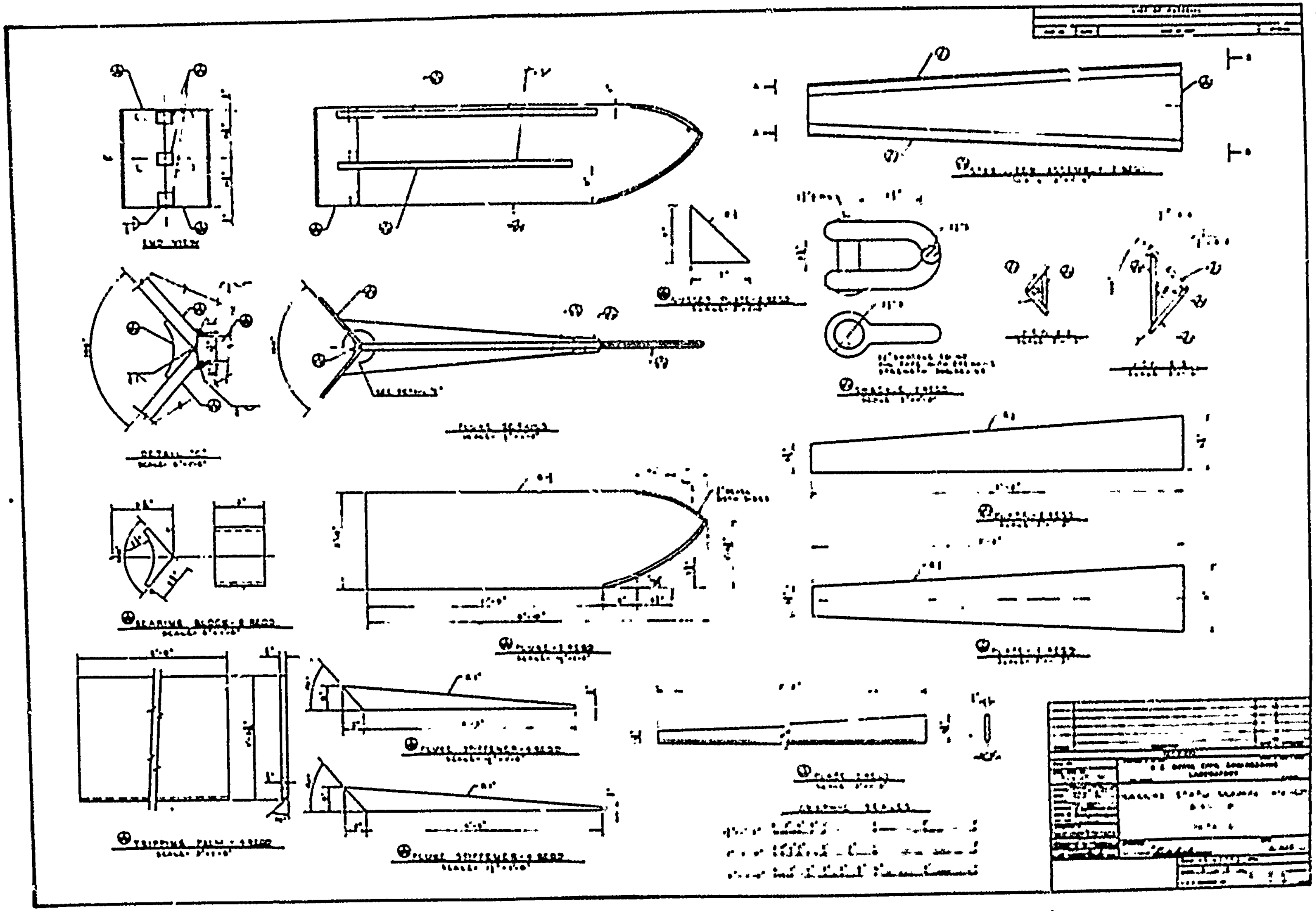
Y & D Drawing No. 813512 BUDOCKS STATO mooring anchor, 3000 lb, details



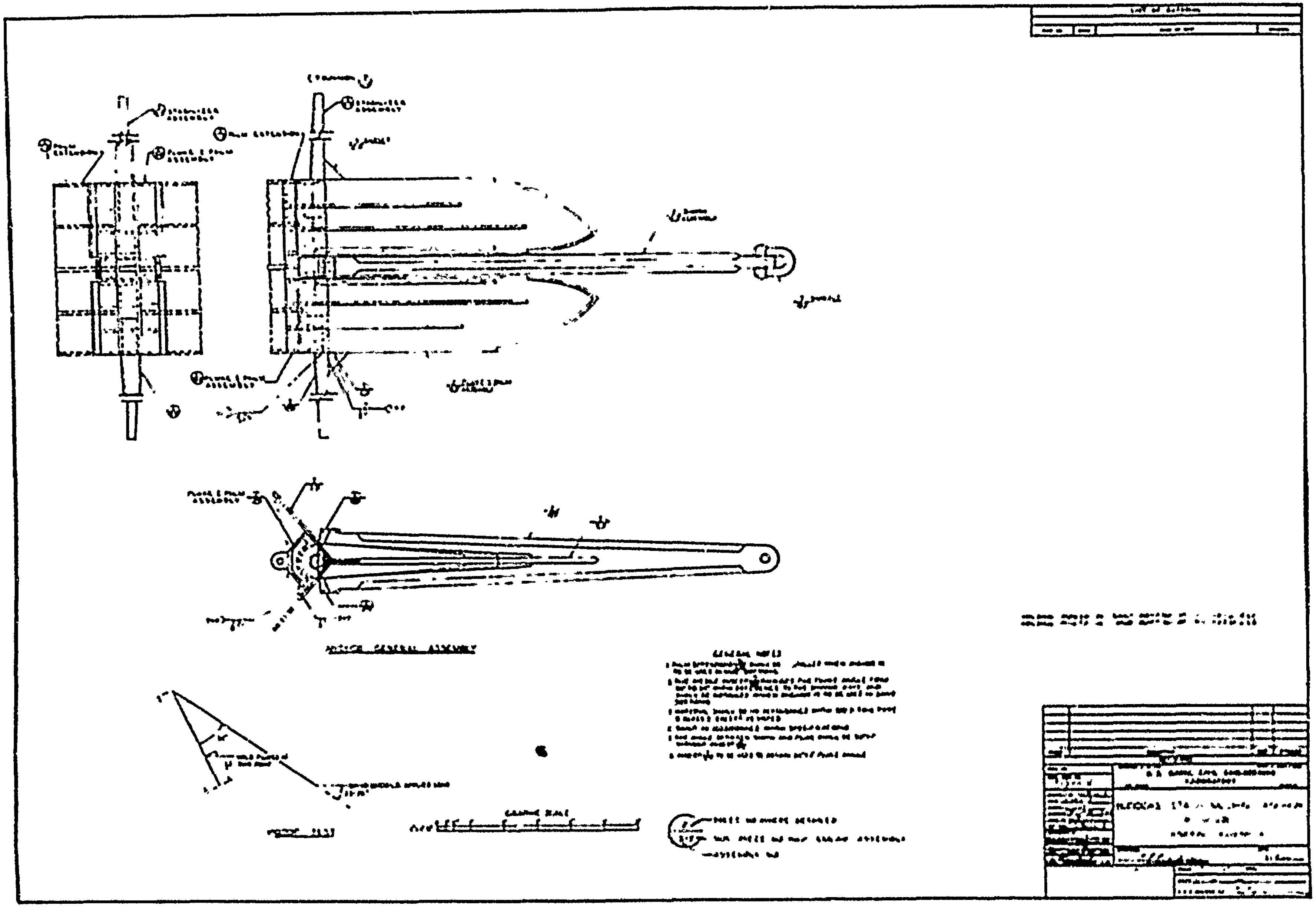
Y & D Drawing No. 813513 BUDOCKS STATO mooring anchor, 6000 lb, general assembly



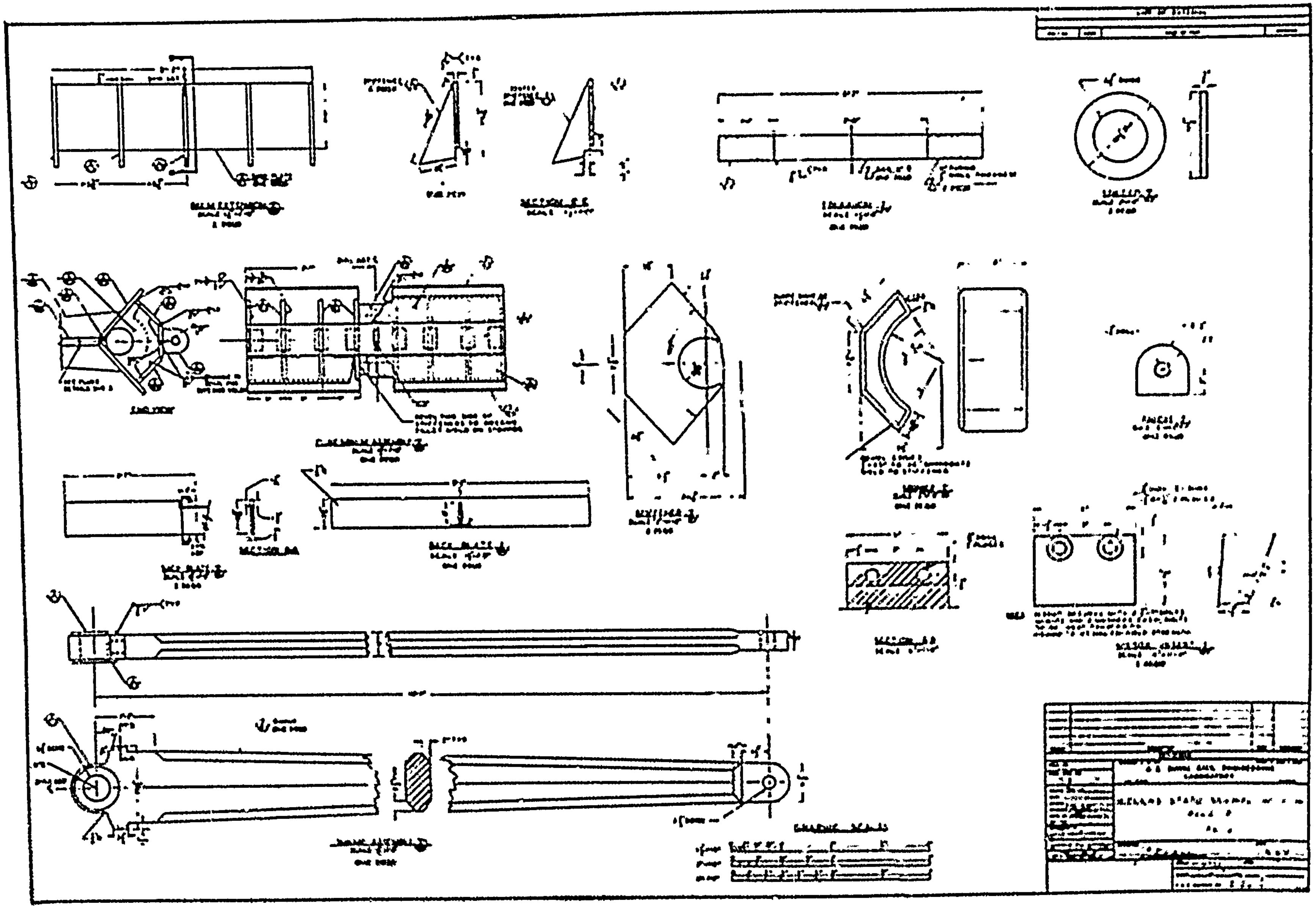
Y & D Drawing No. 813514 BUDOCKS STATO mooring anchor, 6000 lb, details



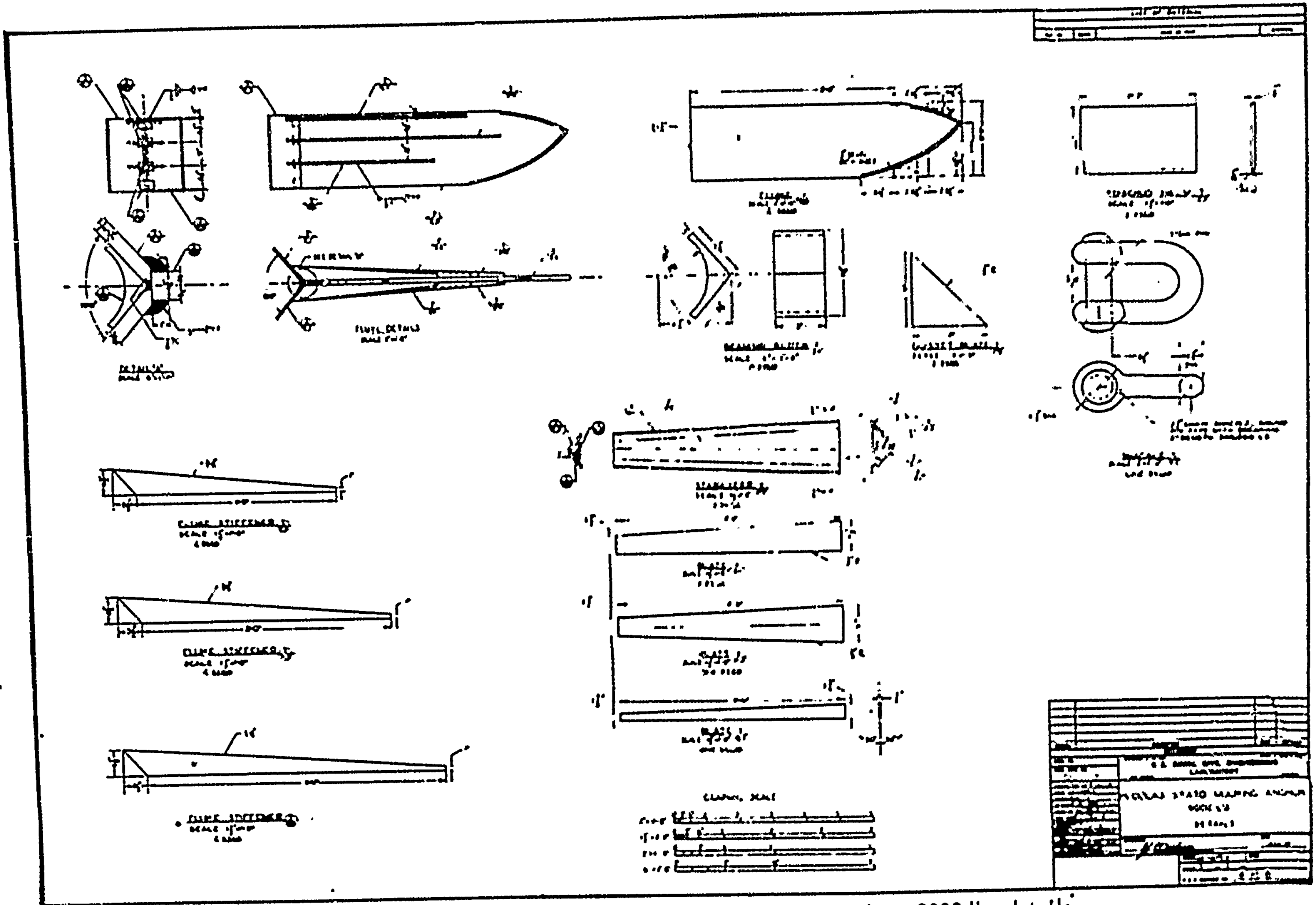
Y & D Drawing No. 813515 BUDOCKS STATO mooring anchor, 6000 lb, details



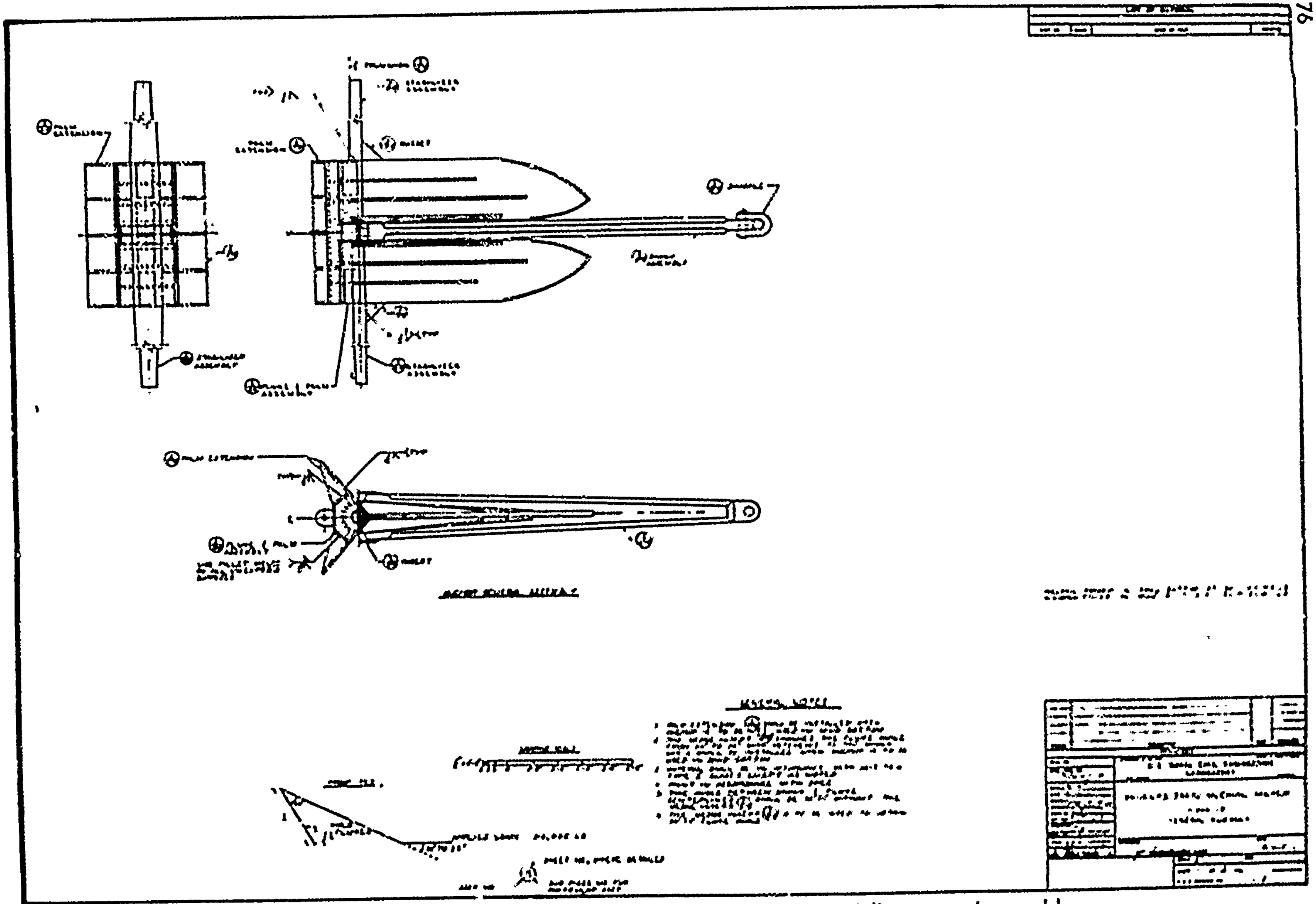
Y & D Drawing No. 813516 BUDOCKS STATO mooring anchor, 9000 lb, general assembly



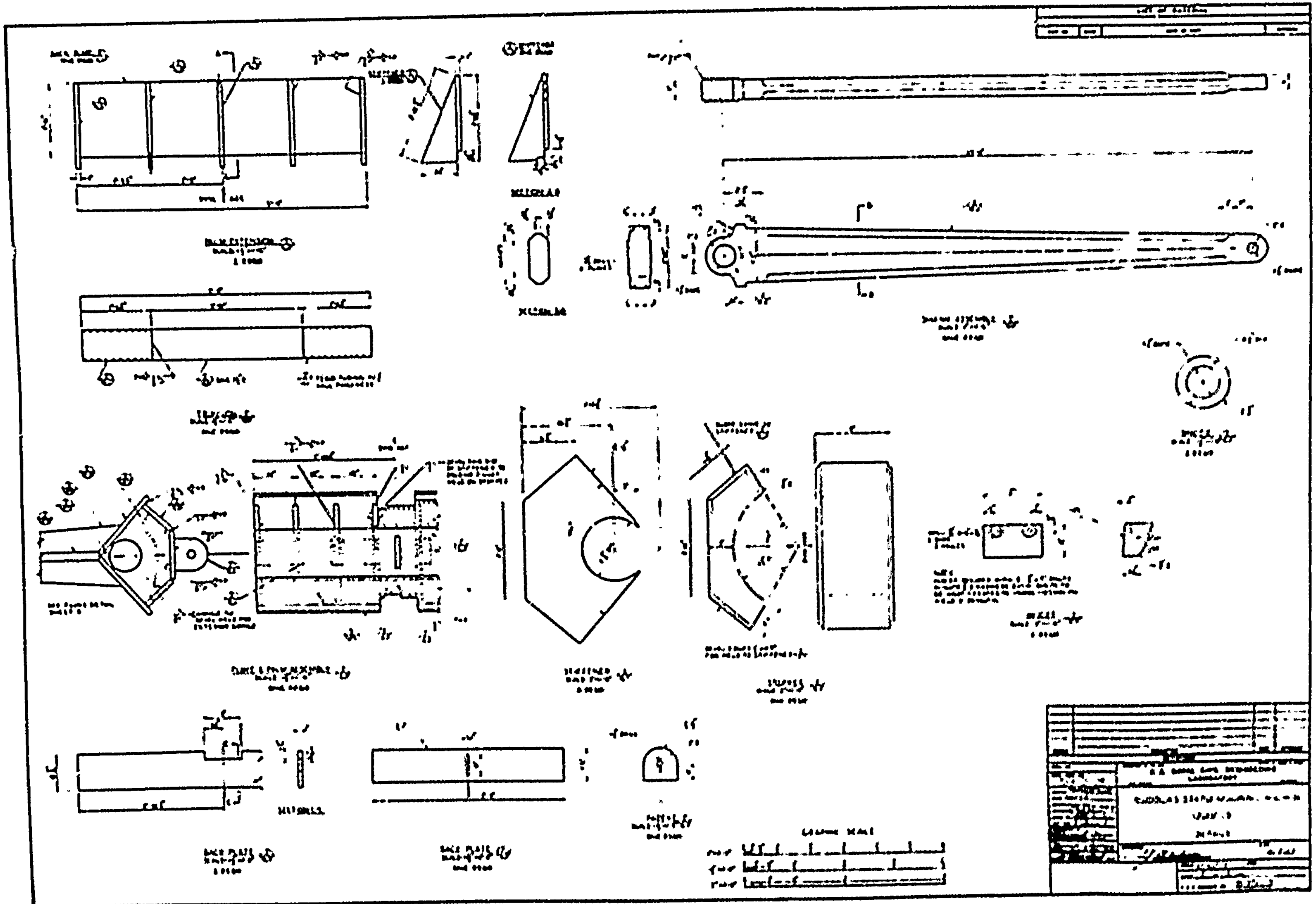
Y & D Drawing No. 813517 BUDOCKS STATO mooring anchor, 9000 lb, details



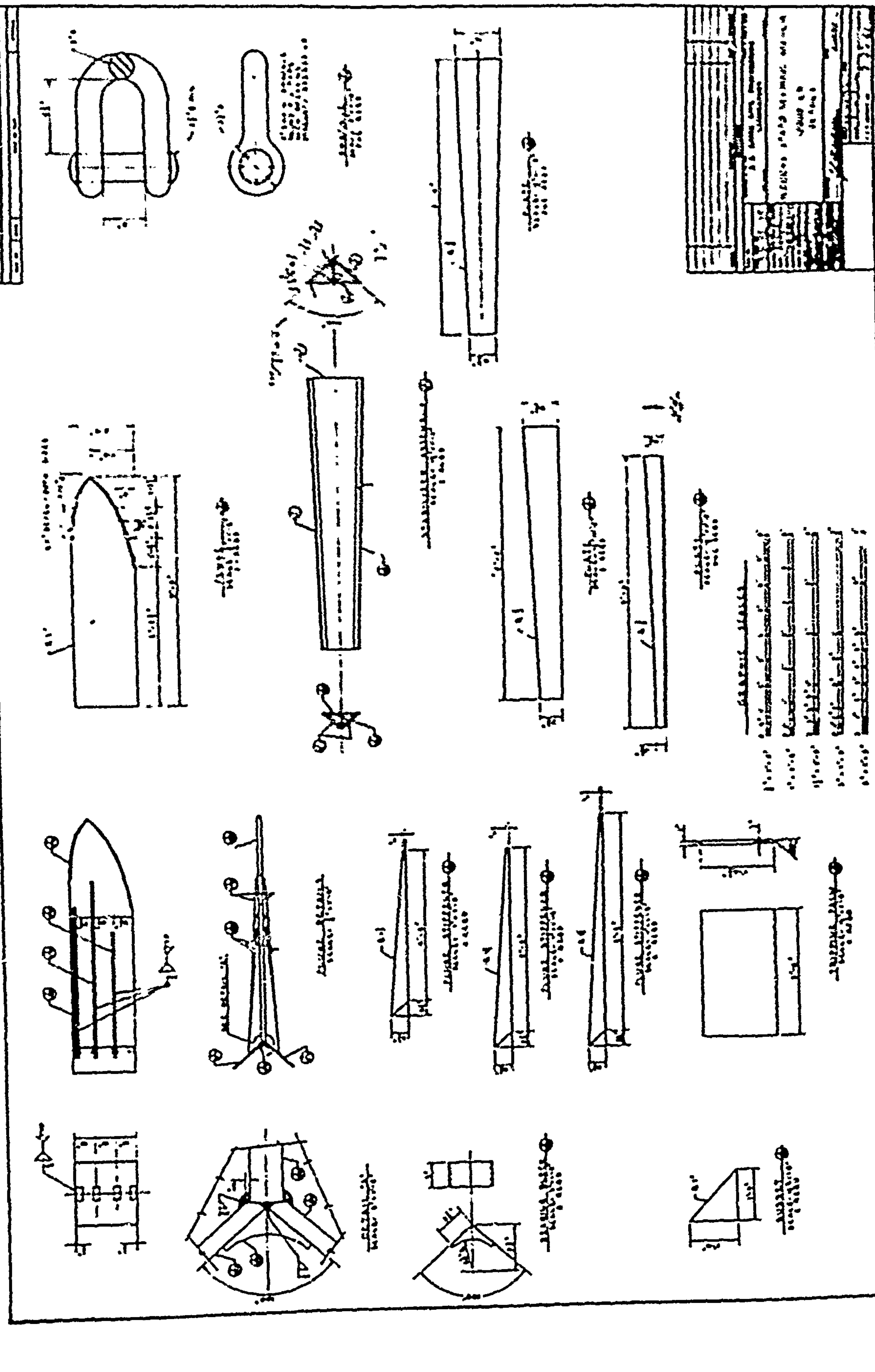
Y & D Drawing No. 813518 BUDOCKS STATO mooring anchor, 9000 lb, details



Y & D Drawing No. 813519 BUDOCKS STATO mooring anchor, 12,000 lb, general assembly



Y & D Drawing No. 813520 BUDOCKS STATO mooring anchor, 12,000 lb, details



Y & D Drawing No. 813521 BUDOCKS STATO mooring anchor, 12,000 lb, details

APPENDIX B

BUDOCKS Report, Sand Samples, 5 January 1950
by L. A. Palmer

Sand tends to bulk or densify during shear such as occurs when an anchor is being dragged through the soil. Movement or shifting of sand particles under water is resisted by the viscosity of water; therefore, sand under water is not as dense in-place as is sand on the shore. Consequently, larger holding-powers will be obtained during beach tests on an anchor than will be obtained during under-water tests.

The soil samples taken during the water tests were given shearing tests after separation and classification of the sands. The sands at the test site were divided into three groups: fine sand, medium sand, and coarse sand. The graduations for the three types of sands are shown in Figures B-1, B-2, and B-3, respectively. In the shearing tests, the initial and final voids ratios were determined for each individual shearing test. The voids ratio is the volume of voids divided by the volume of solids in a given volume of sand. Thus, in a cubic foot of sand having a voids ratio of 0.50, the volume of solids is twice the volume of voids, or 2/3 cu foot, and the volume of total voids is 1/3 cu foot. The lower the voids ratio, the greater the unit weight of the soil.

In practically all shearing tests, the sand either bulks or densifies during shear. This volume increase or decrease is determined by two conditions: the initial voids ratio before shearing, and the system of applied load. Since, with sand, the relation between the principal stresses is fixed at any instant and at any given voids ratio during shear, it follows that the volume change during shear is controlled by the initial voids ratio and the magnitude of the minor principal stress during shear.

The relationships between the stresses for the case of axial symmetry is shown in Figure B-4; s being the shearing stress on the surface of shear and p_1 and p_2 being the major and minor principal stresses, respectively. This is the well-known Mohr diagram.

If a sample shears at constant volume, the initial voids ratio is the critical voids ratio of the material. To every critical voids ratio, there corresponds a fixed and definite value of minor principal stress, p_2. If the initial voids ratio, e, is below the critical value, the sample bulks during shear, the volume increase being proportional to the extent to which the initial e is below the critical value. If the initial voids ratio is above the critical e, the sample compacts during shear to an extent that is proportional to the difference between the actual initial e and the critical value. At the critical value, the sand shears with neither bulking nor compaction. This is the critical e, or zero line. Figures B-5, B-6, and B-7 show the fine, medium, and coarse sands respectively.

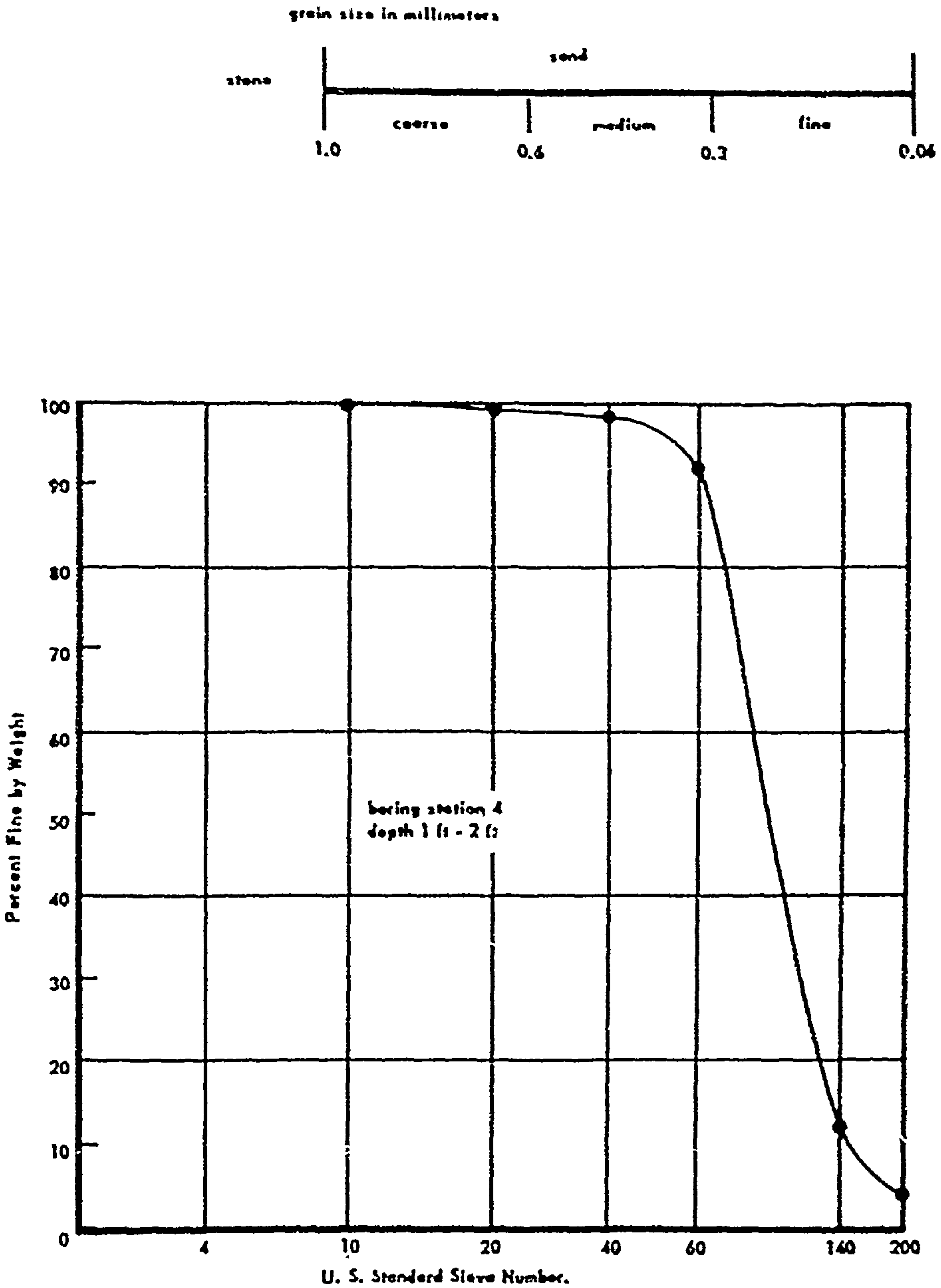


Figure B-1. Mechanical soil analysis of fine sand at the test site.

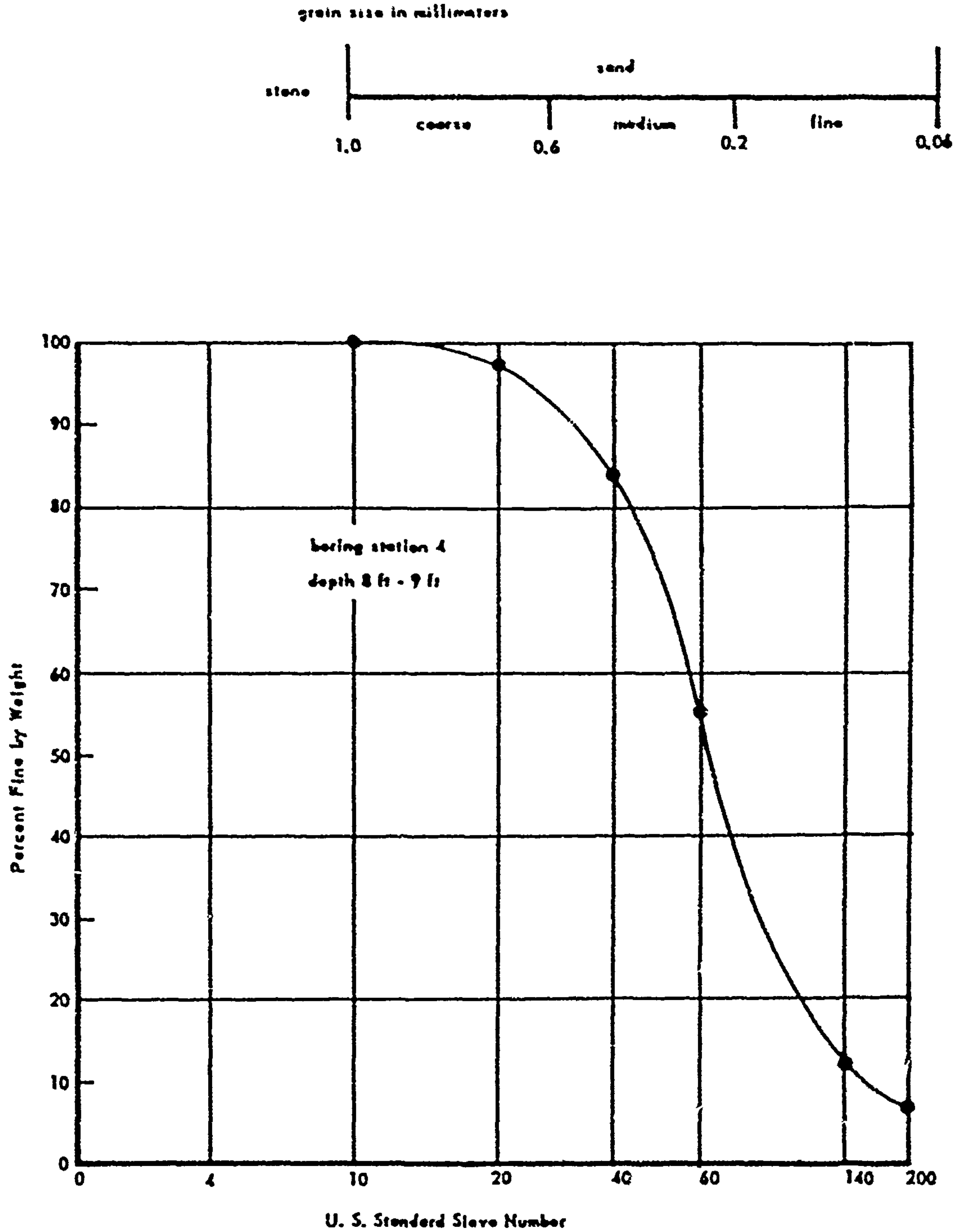


Figure B-2. Mechanical soil analysis of medium sand at the test site.

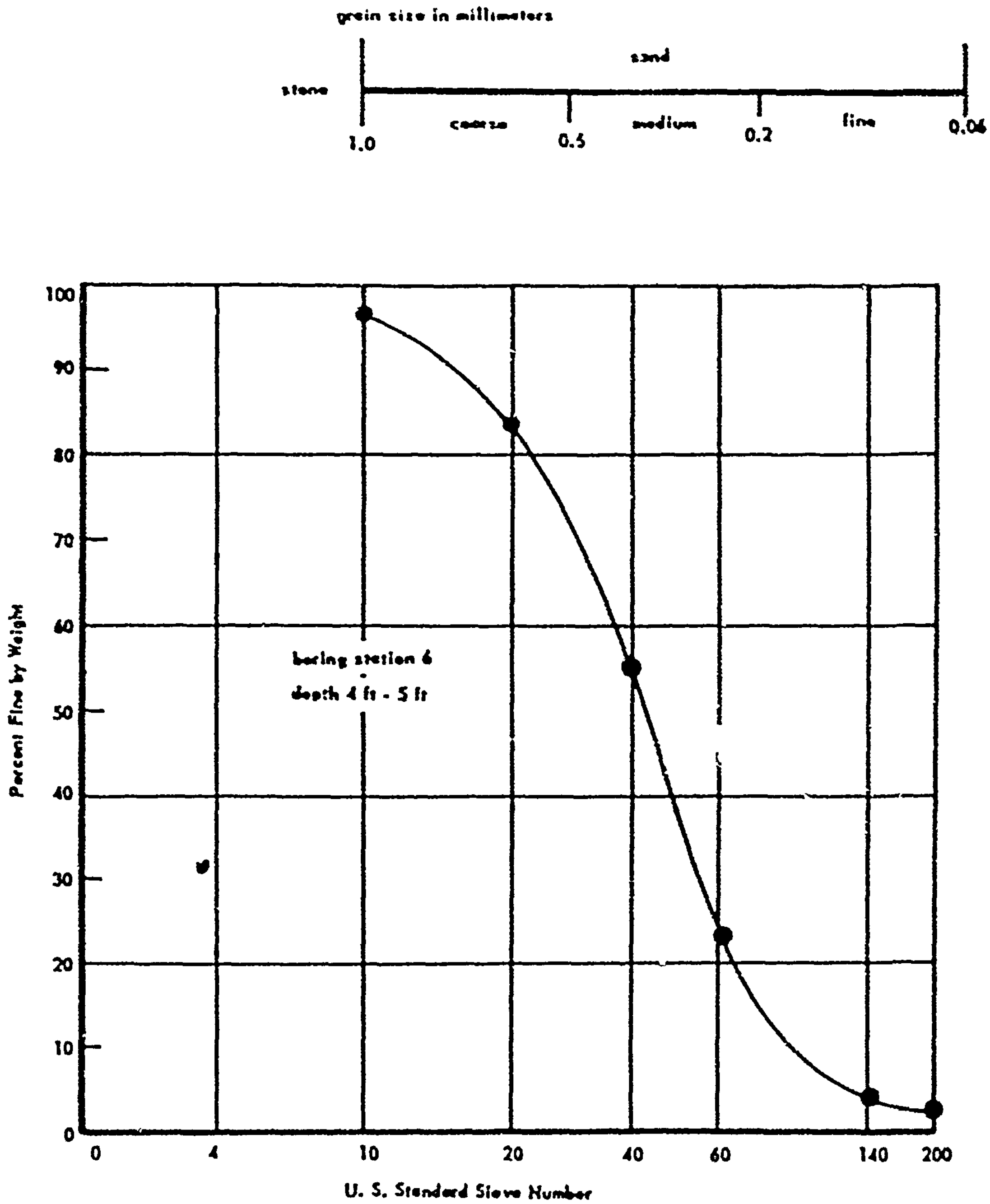
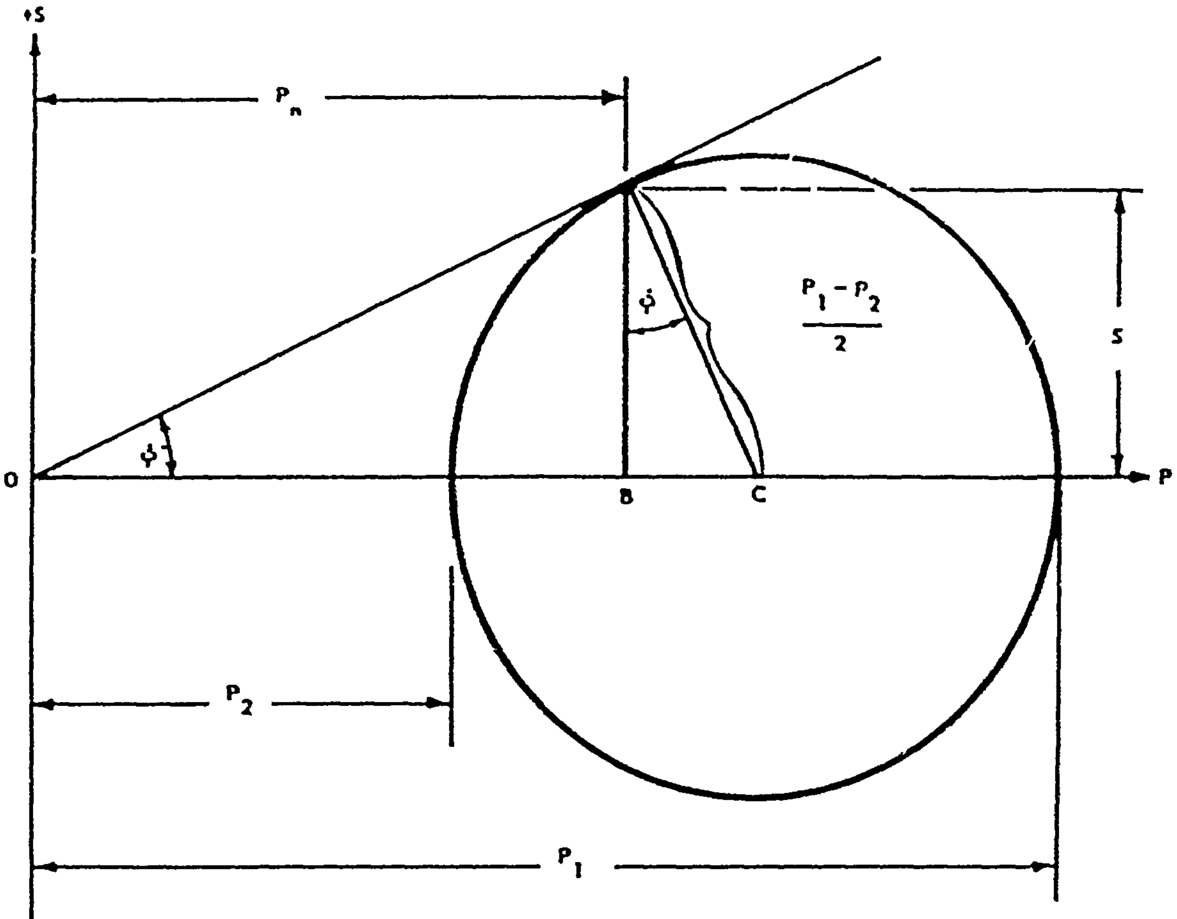


Figure B-3. Mechanical soil analysis of coarse sand at the test site.



$$S = P_n \tan \phi$$

$$P_n = OB = OC - BC = \frac{P_1 - P_2}{2} - \frac{P_1 - P_2}{2} \sin \phi$$

$$= \frac{P_1 (1 - \sin \phi) + P_2 (1 + \sin \phi)}{2}$$

or, since

$$P_1 (1 - \sin \phi) = P_2 (1 + \sin \phi)$$

then

$$P_n = P_2 (1 + \sin \phi)$$

so that

$$S = P_2 (1 + \sin \phi) \tan \phi$$

Figure B-4. Mohr diagram of cohesionless earth failure.

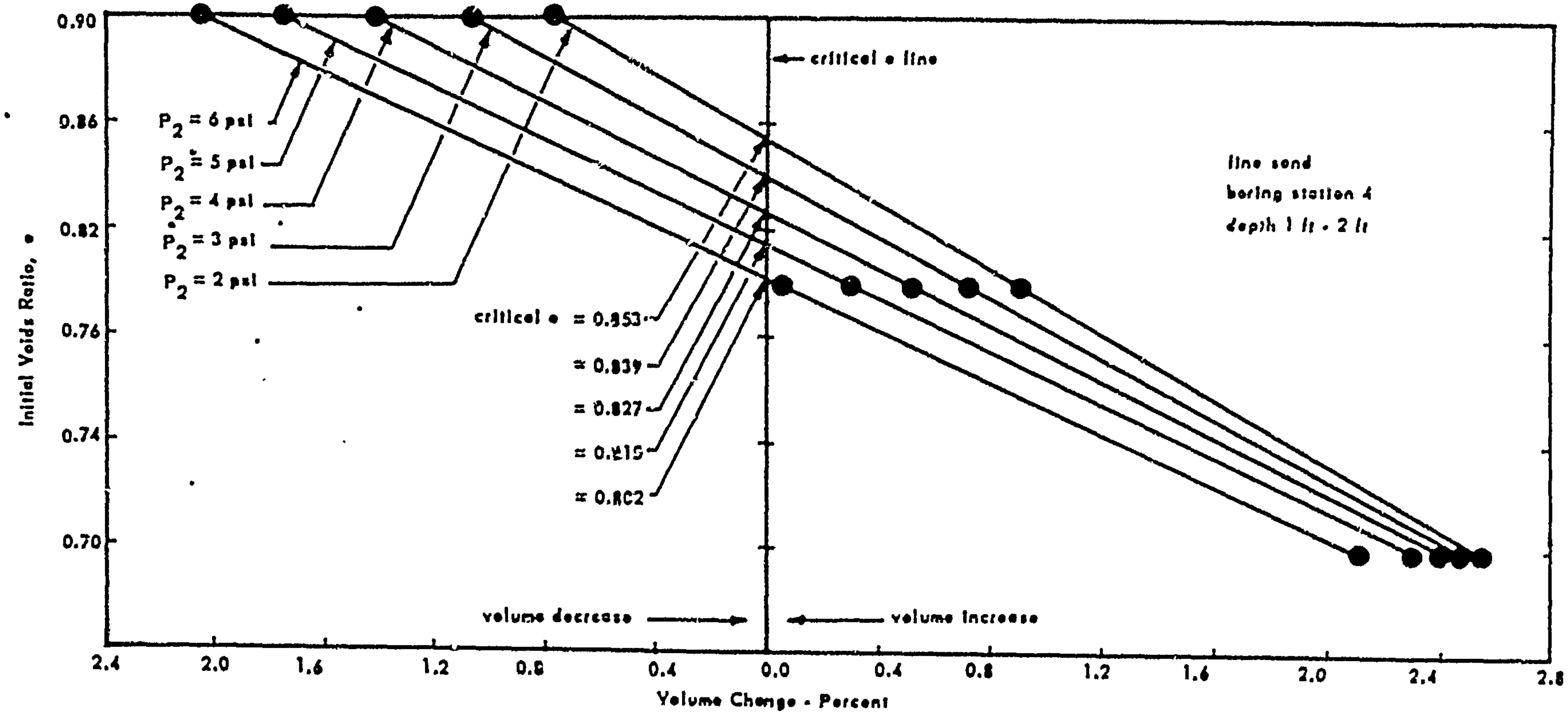


Figure B-5. Voids ratio vs volume change for fine sand at the test site.

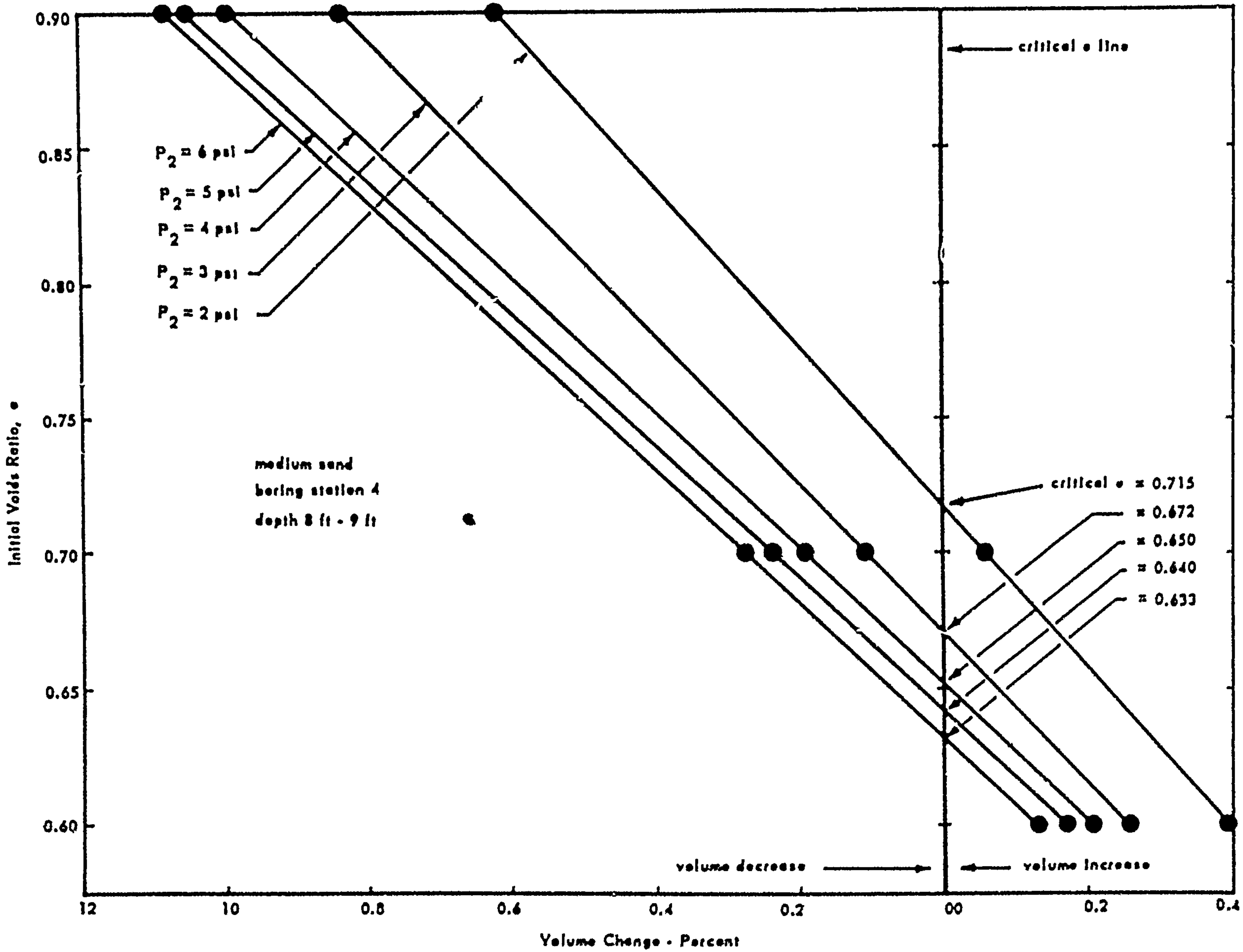


Figure B-6. Voids ratio vs volume change for medium sand at the test site.

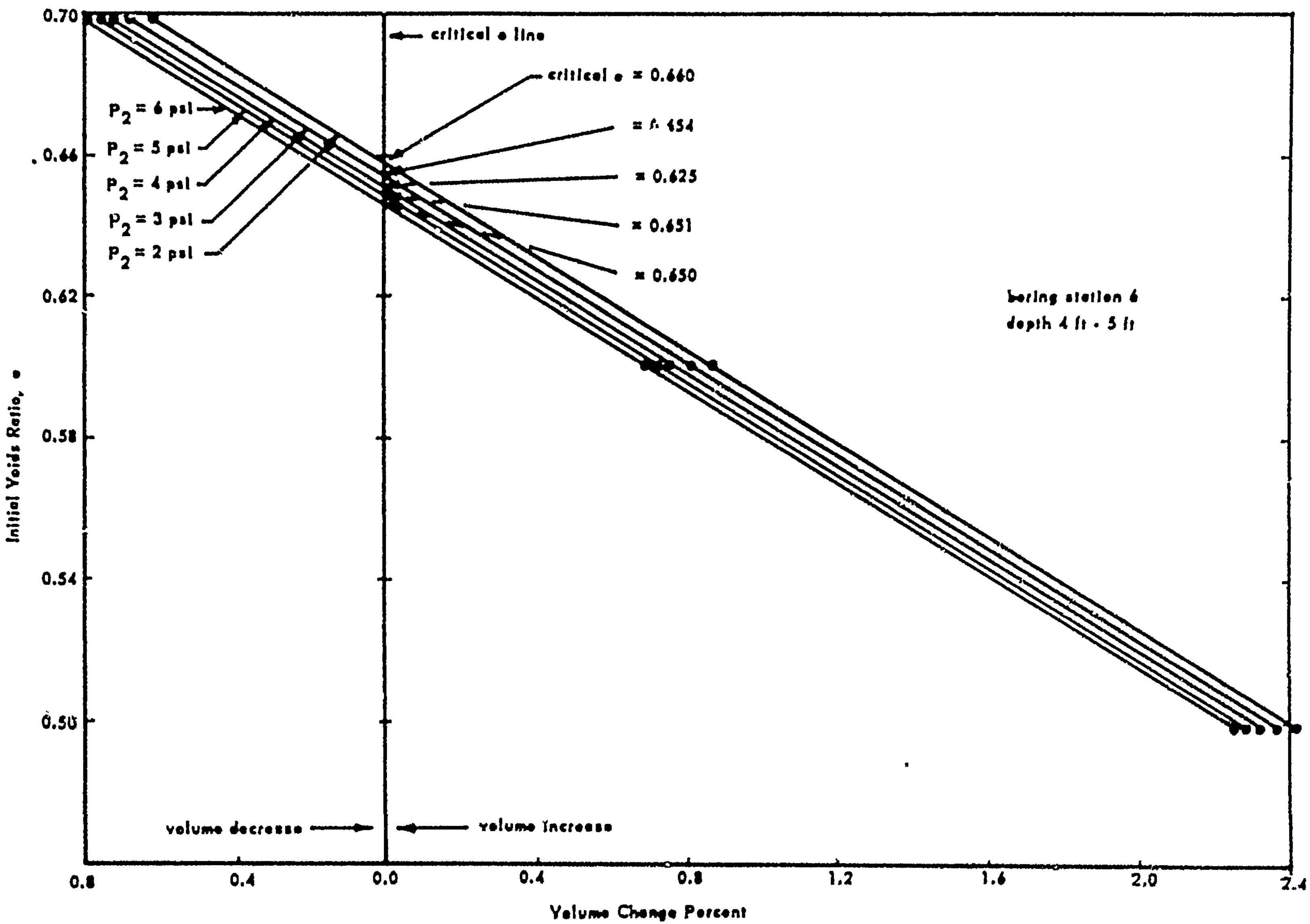


Figure B-7. Voids ratio vs volume change for coarse sand at the test site.

The angle of internal friction also changes as the sand bulks or compacts. This angle varies within wide limits in the same sand. The relations between the critical e and p_2 are shown in Figures B-8, B-9, and B-10. The relations between the initial e and the angle of internal friction for the fine, medium, and coarse sands, respectively, are further shown in Figures B-11, B-12, and B-13.

A study was made to determine the stress analysis for an anchor being dragged through sand; but, because of the large variable factors in the test, no precise data could be obtained. However, it is possible to obtain some indication of the effect of variations in the sand density on the resistance to anchor pull; that is, with a given anchor and a given sand bottom, how much the resistance to pull may be made to vary by bulking or densifying the sand, keeping all other variable factors such as angle of pull, depth of penetration, etc., constant.

Sand	Initial e	Initial Ø	Range in e	Range in Ø
Fine	0.9	30.0	0.3	7.4
Fine	0.6	37.4	—	—
Medium	0.9	25.0	0.3	20.0
Medium	0.6	45.0	—	—
Coarse	0.7	35.4	0.2	10.4
Coarse	0.5	45.8	—	—

The frictional resistance varies more with e in the case of medium and coarse sand than in the case of fine sand. This observation may be true only for the sand in the test area. Also, there is a wider range in initial e variability for fine and medium sands than for coarse sand. This follows because it is easier to densify a cubic foot of loose sand by shaking than to densify a cubic foot of baseballs by shaking.

It is possible that repeated dragging of an anchor over the same route in sand will eventually bring the sand along the path of pull to its critical density corresponding to the minor principal stress developed by the pulling force. That is, if the sand in-place is initially dense, repeated dragging of the anchor will progressively bulk the sand until a limit is reached; and, if the sand in-place is initially loose, repeated anchor pulls will densify it, within a limit. The limit would be the condition of critical density. When this limit is attained, subsequent variations in resistance to pull would be due to variable factors other than the shearing resistance of the sand.

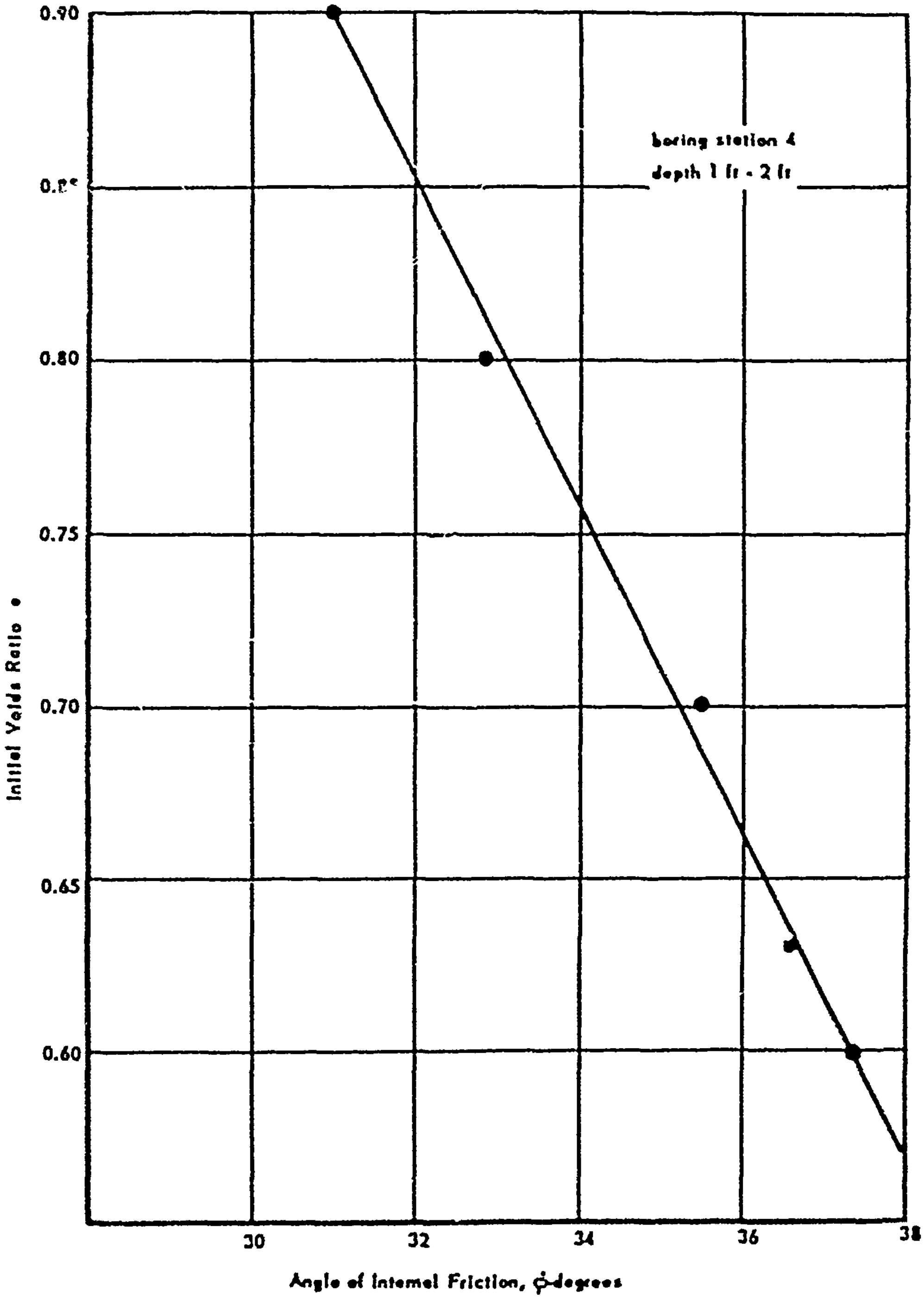


Figure B-8. Voids ratio vs angle of internal friction for fine sand at the test site.

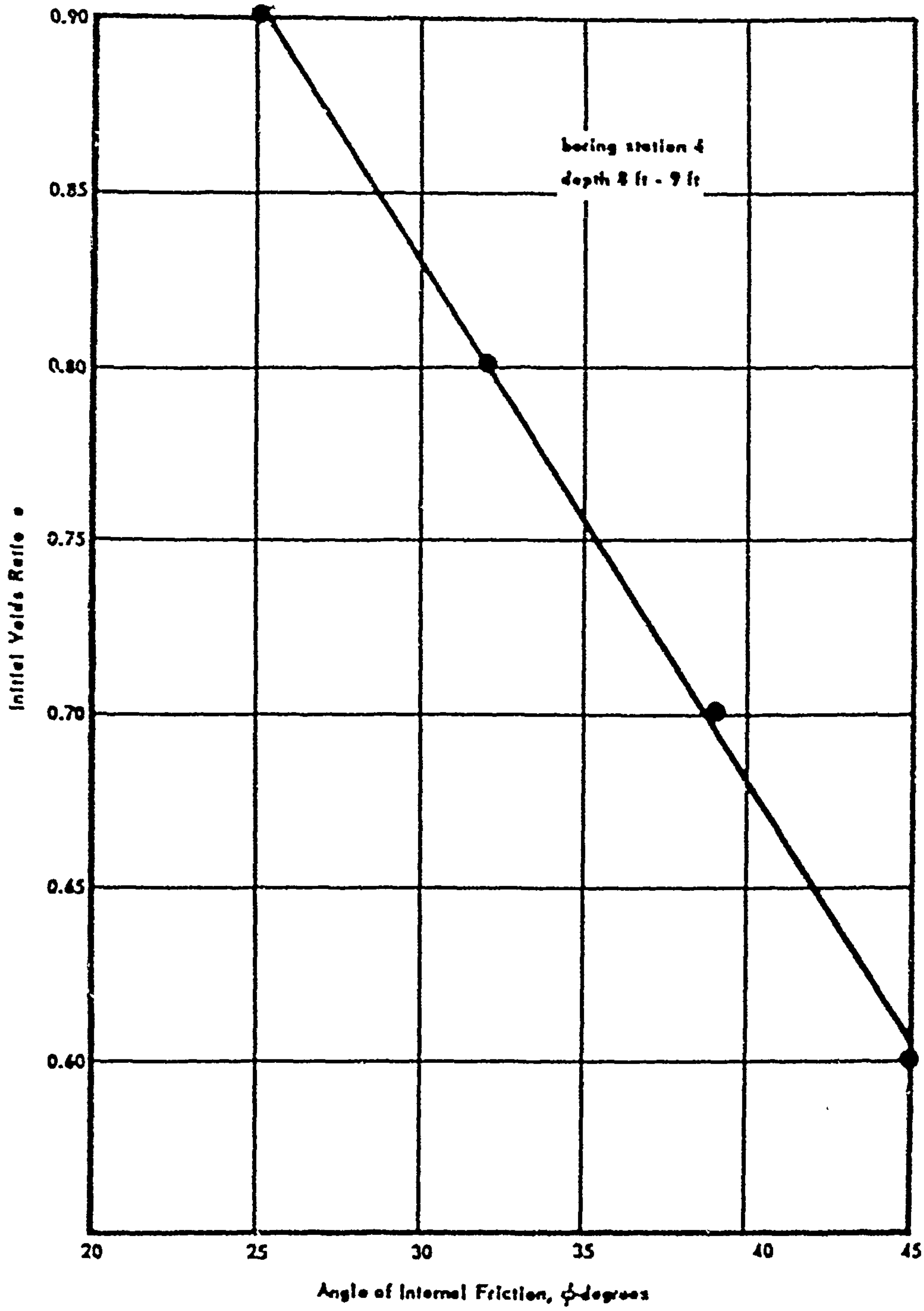


Figure 6-9. Voids ratio vs angle of internal friction for medium sand at the test site.

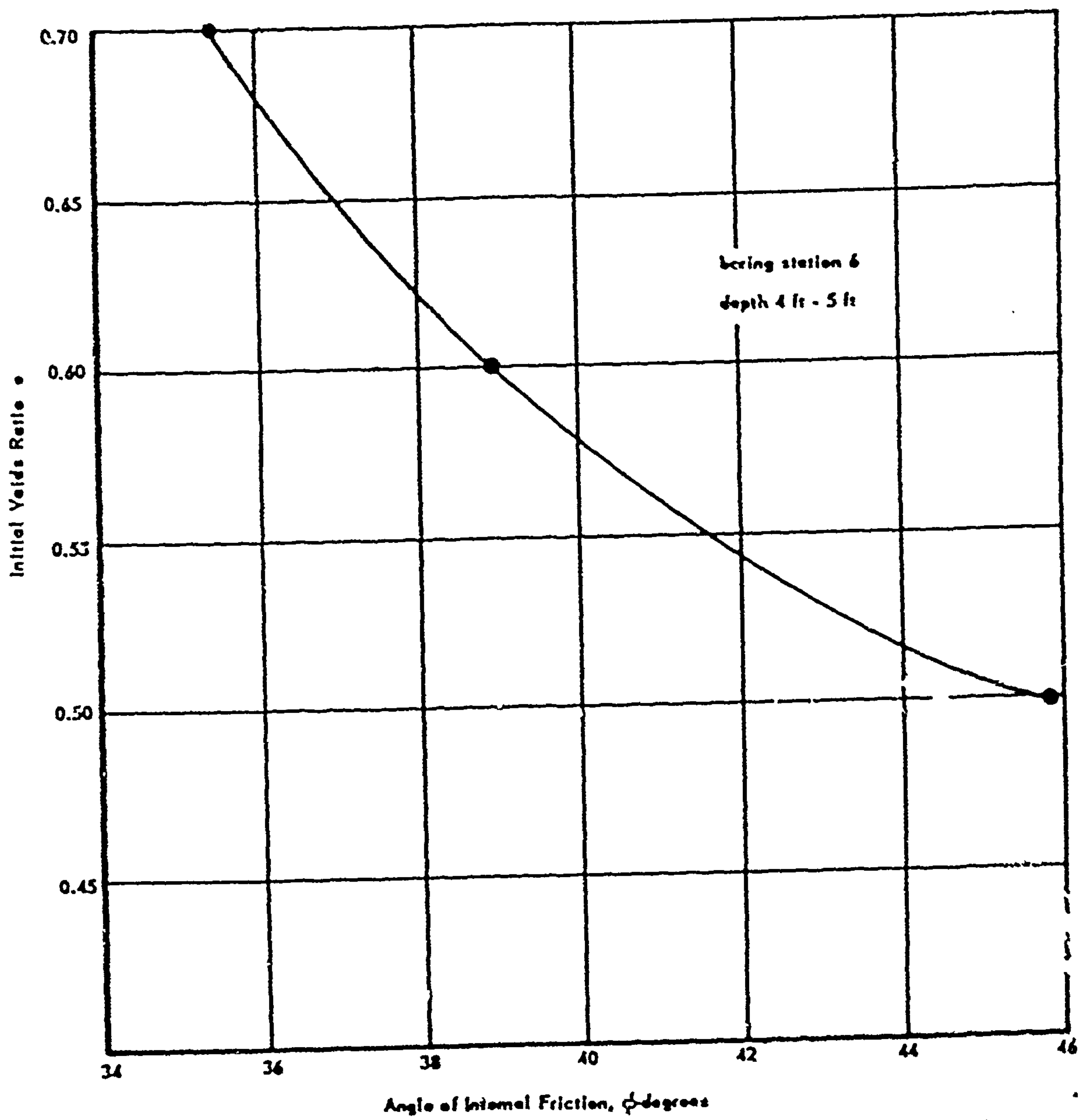


Figure B-10. Voids ratio vs angle of internal friction for course sand at the test site.

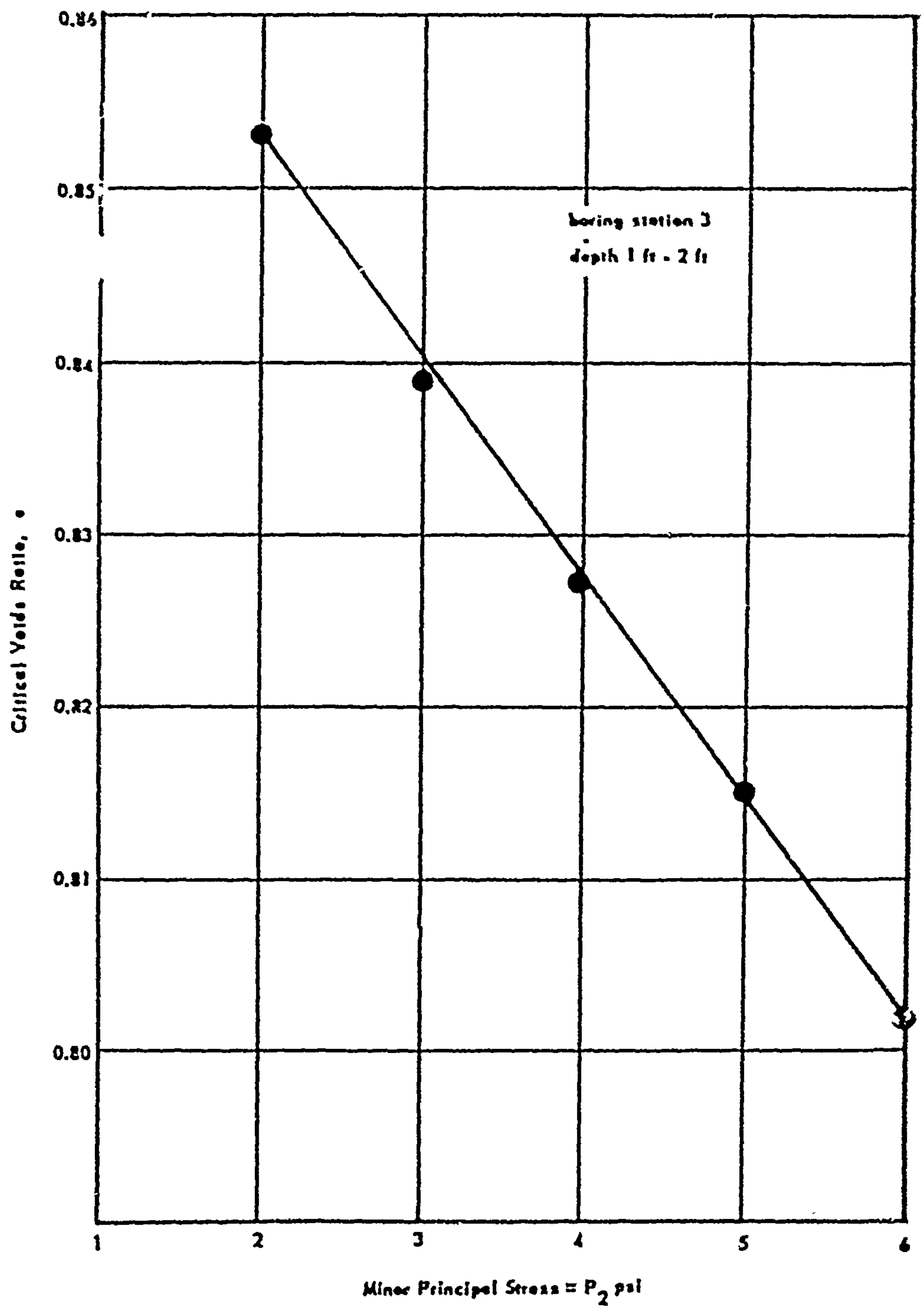


Figure B-11. Relation between voids ratio and minor principal stress for fine sand at the test site.

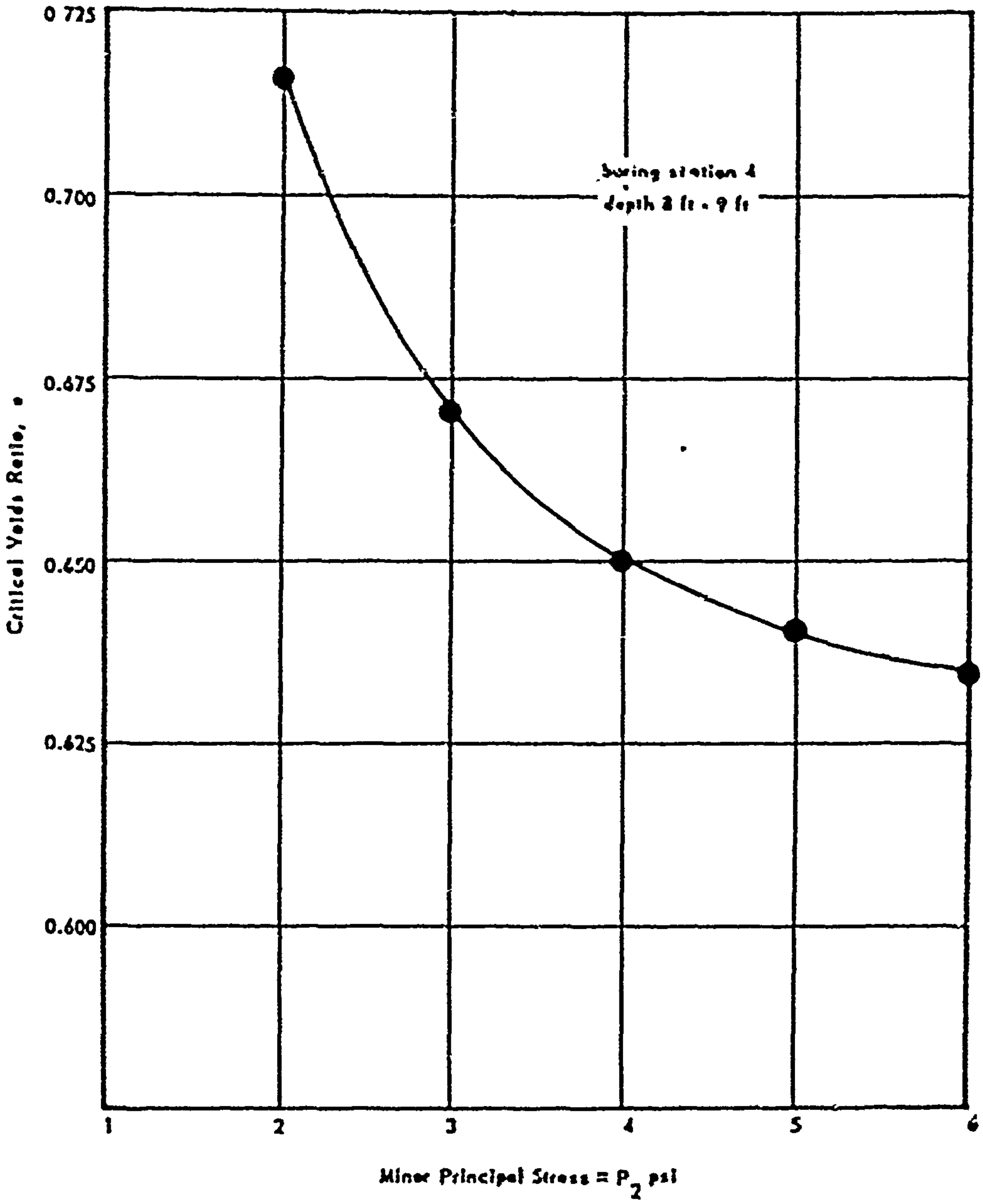


Figure B-12. Relation between voids ratio and minor principal stress for medium sand at the test site.

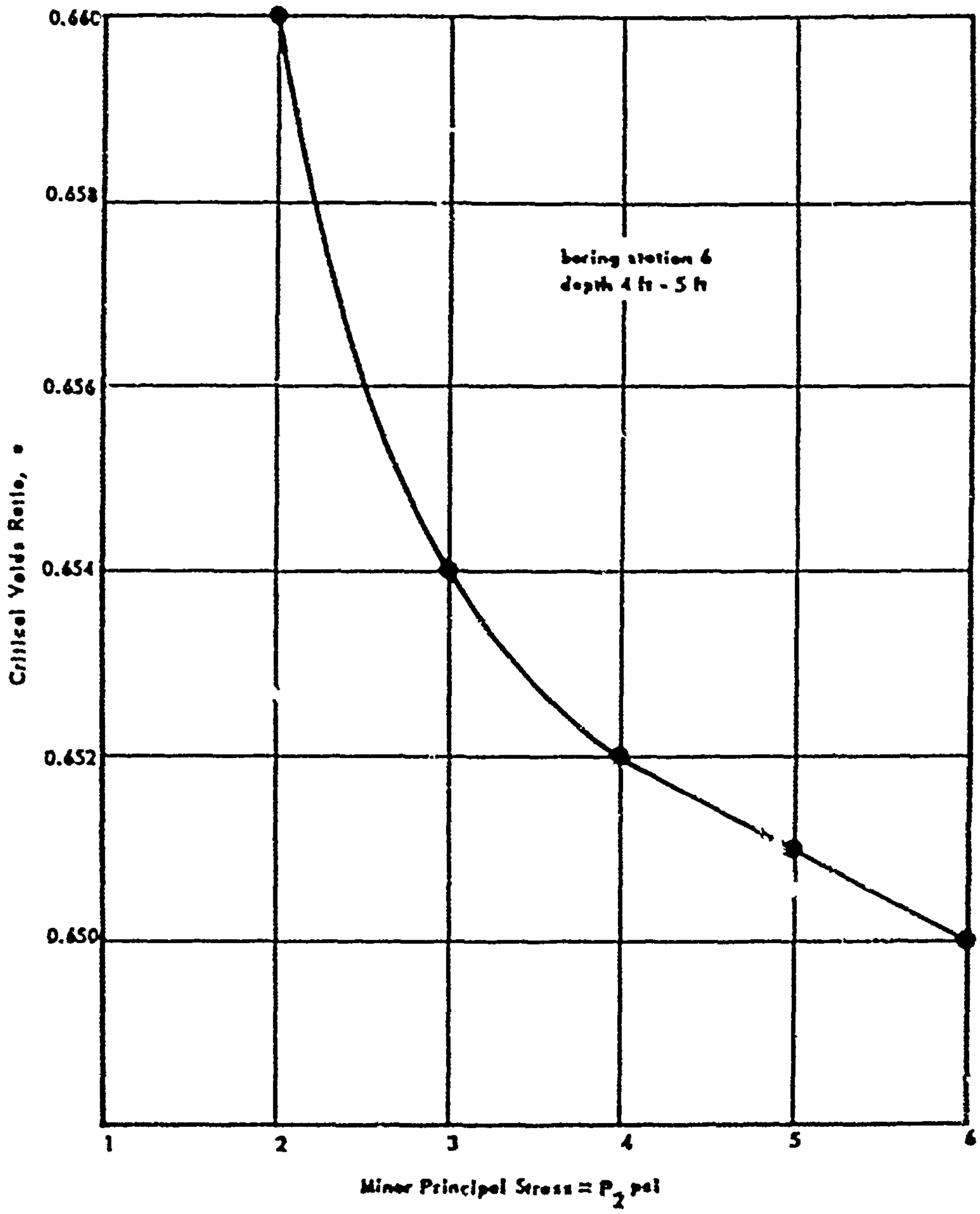


Figure B-13. Relation between voids ratio and minor principal stress for coarse sand at the test site.

One important property to study, where anchors are dragged in sand bottom, is the relation of critical density to stress, the s corresponding to various initial e values.

From the last equation for s (see Figure 8-7), the variations in anchor pull caused solely by variations in initial e of the sand are shown in the following table.

Sand	Initial e	Sin Ø	Tan Ø	$s = p_2 (1 + \sin Ø)\ \tan Ø$
Fine	0.9	0.515	0.600	0.91
Fine	0.6	0.607	0.765	1.23
Medium	0.9	0.423	0.466	0.66
Medium	0.6	0.707	1.000	1.71
Coarse	0.7	0.579	0.710	1.12
Coarse	0.5	0.717	1.030	1.77

Example: suppose that p_2 is the weight of submerged sand above the center of area of the surface of an anchor opposed to the line of drag. If the depth is 8 ft in submerged sand p_2 is about 0.5 kips; then:

for the fine sand,

$$s = 0.5 \times 0.91 = 4.55 \ \text{k/ft}^2$$

$$\text{or } s = 0.5 \times 1.23 = 6.15 \ \text{k/ft}^2$$

depending upon whether the initial voids ratio is 0.90 or 0.60.

s = unit shearing resistance

for the medium sand,

corresponding values for s are

$$s = 3.30 \ \text{k/ft}^2 \text{ or } 8.55 \ \text{k/ft}^2$$

depending on whether the initial e is 0.90 or 0.60.

for the coarse sand,

$$s = 5.60 \ k/ft^2 \ \text{or} \ 8.85 \ k/ft^2$$

depending on whether the initial e is 0.70 or 0.50.

For the medium sand, the percentage increase in s by decreasing e from 0.90 to 0.60 is:

$$\frac{8.55 - 3.30}{3.30} \times 100 = 160 \text{ percent, approximately.}$$

Actually, the increases in total shearing resistance are considerably greater than may be indicated because the surface of shear tends to be increased in area or extent as the voids ratio is decreased and the angle of internal friction increased. It must be remembered that total, and not unit-shearing, resistance is considered, and that the shearing surface has reference to that developed by the anchor.

APPENDIX C

Computation for Chain Lengths used During Anchor Tests

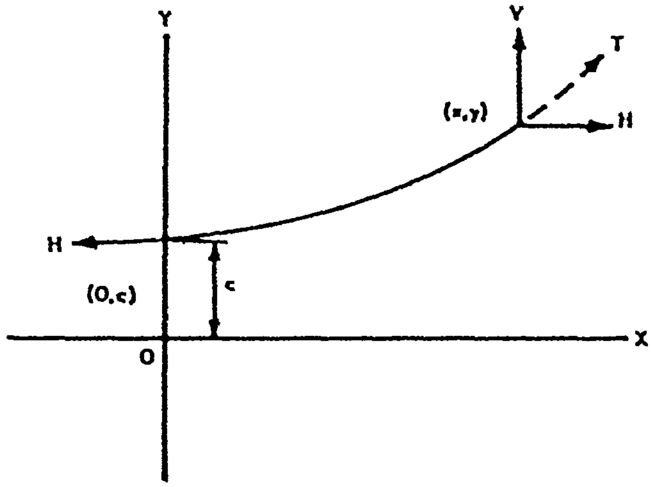


Figure C-1. Catenary curve.

The chain lengths were obtained by relations as follows (shown in Figure

At point (x, y)

$V = ws$ — H = horizontal force at point (x, y)

$H = wc$ — V = vertical force at point (x, y)

$T = wy$ — T = axial tension at point (x, y)

Equations of a catenary — s = length of curve from point (0,c) to (x, y)

$$y^2 = s^2 = c^2$$

w = weight of chord per unit length

$$y = c \cosh \frac{x}{c}$$

$$s = c \sinh \frac{x}{c}$$

An example of the calculations for computing the chain length for an 12,000-lb anchor is as follows:

Example:

Maximum holding power of 12,000-lb anchor, $H = 220{,}000$ lb

Chain = 2-3/4" Cast Steel anchor chain

Weight (lb) of 15-fathom shot of chain when submerged in sea water

$= 743d^2 = 5{,}616$ lb

d = wire diameter of chain in inches

Weight per foot in sea water = 62.4

$c = H/w$

$c = 220{,}000/62.4 = 3525$ ft

since the slope at the anchor is to be zero then the anchor is at point $(0, c)$.

The rise from the anchor to the instrument car = 15 ft therefore, at the upper end of the chain, point (x, y),

$$y = 3525 + 15 = 3540$$

now $y^2 = s^2 + c^2$

or $s^2 = y^2 - c^2$

therefore, at point (x, y) $s = \sqrt{3540^2 - 3525^2} = 355$ ft

Total length of chain required (including 5 ft from bow of car to dynamometer) $355 + 5 = 360$ ft.

Stress in chain at upper end =

$$T = wy = 62.4 \times 3540 = 220{,}896$$

APPENDIX D

Computations of Anchor Holding Power Confidence Limits

Computations of Anchor Holding Power Confidence Limits:

Typical Example: 12,000 lb Mooring Anchor - Mud Bottom

H.P. kips at 50 ft	Avg. H.P. at 50 ft	Dev.	Dev. Sq.	Variance	Std. Dev.
183.4		- 2.1	4.41		
192.6		+ 7.1	50.41		
145.3	185.5	-40.2	1616.04		
179.3		- 6.2	38.44		
201.6		+16.1	259.21		
210.8		+25.3	640.09		
			2608.60	521.72	22.84

Variance = dev. sq. ÷ (n-1) = 521.72

Standard deviation = $\sqrt{\text{variance}}$ = 22.84

Variance of averages = variance ÷ no. of tests = 521.72 ÷ 6 = 86.95

Standard deviation of average = $\sqrt{86.95}$ = 9.32

Confidence interval limits = $185.5 \pm t\sqrt{\dfrac{\text{var. for tests}}{\text{no. of tests}}}$

$$185.5 \pm (2.57)\ (9.32) = 185.5 + 23.95 + 209.45 \text{ kips}$$

$$185.5 - 23.95 = 161.55 \text{ kips}$$

The confidence interval for average = 209.45 and 161.55 at 95 percent confidence level.

n - 1 = number of tests minus 1 = 5

t = Students 't' distribution for degrees of freedom = 2.57 at 95 percent confidence level.

degrees of freedom = number of tests minus 1 = 5

APPENDIX E

Graphs of individual test pulls at 0-, 6-, and 12-degree chain angles of all BUDOCKS STATO anchors tested in sand and mud bottoms

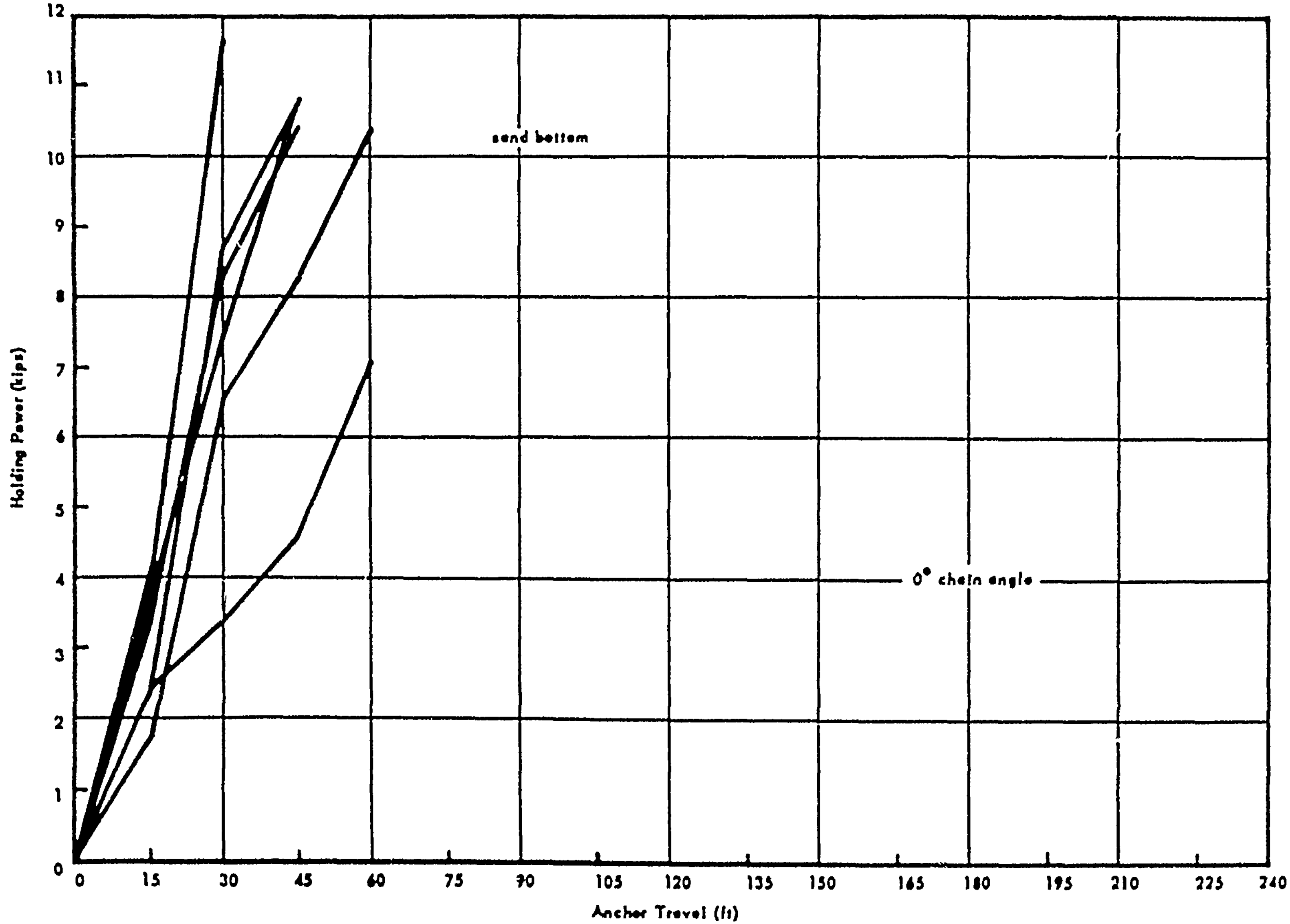


Figure E-1. Graph of test pulls on 200-lb STATO mooring anchor.

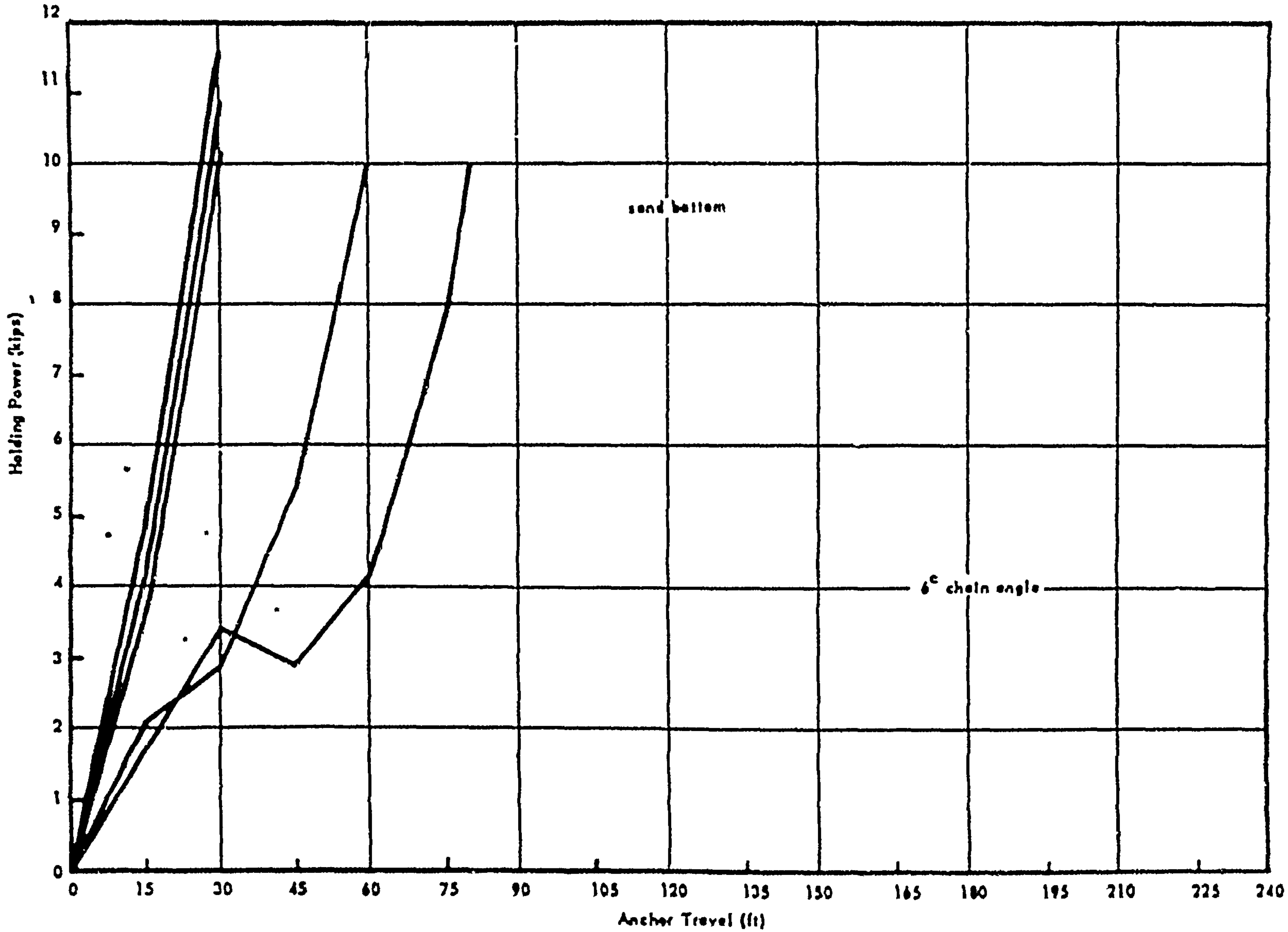


Figure E-2. Graph of test pulls on 200-lb STATO mooring anchor.

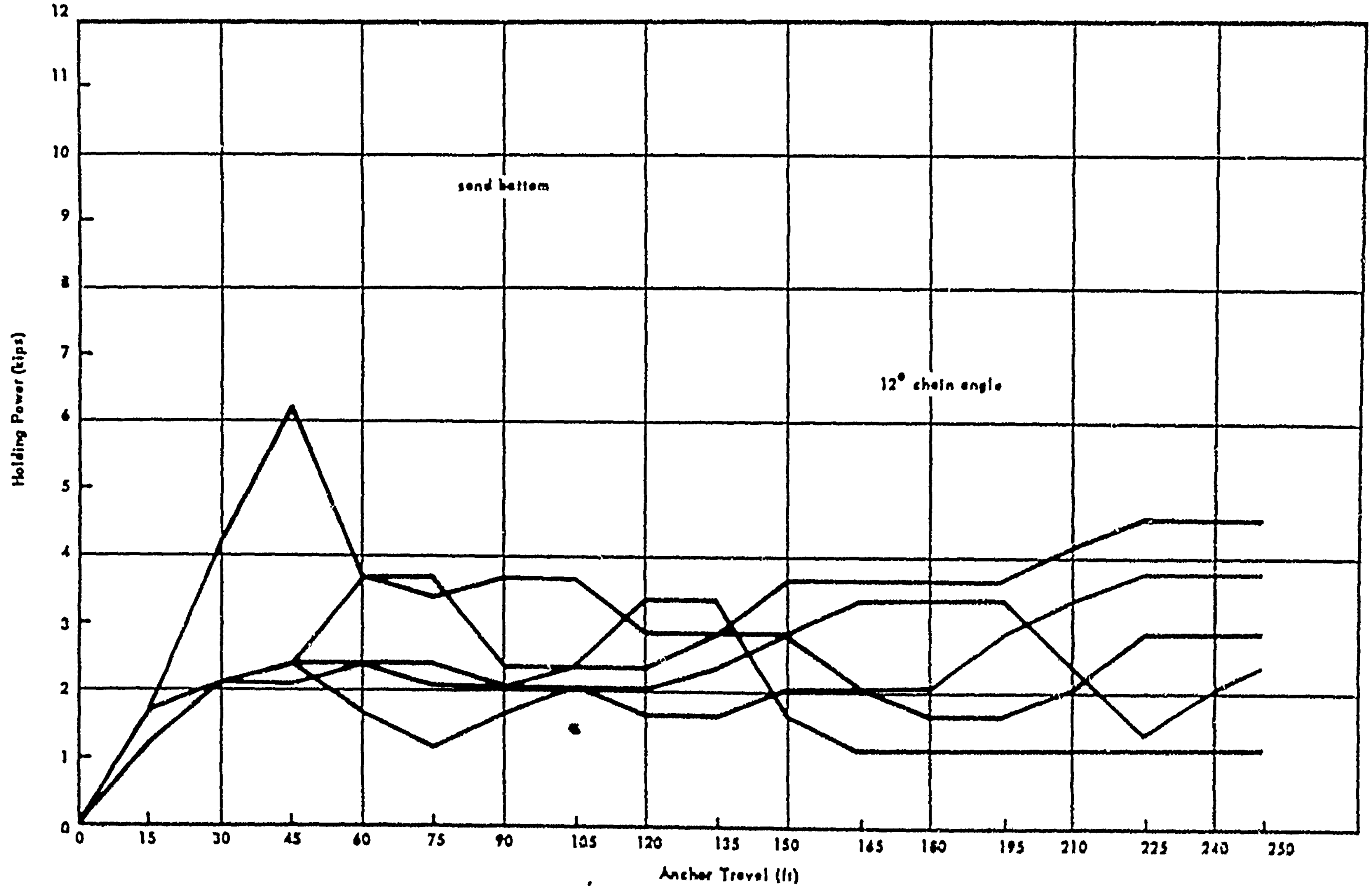


Figure E-3. Graph of test pulls on 200-lb STATO mooring anchor.

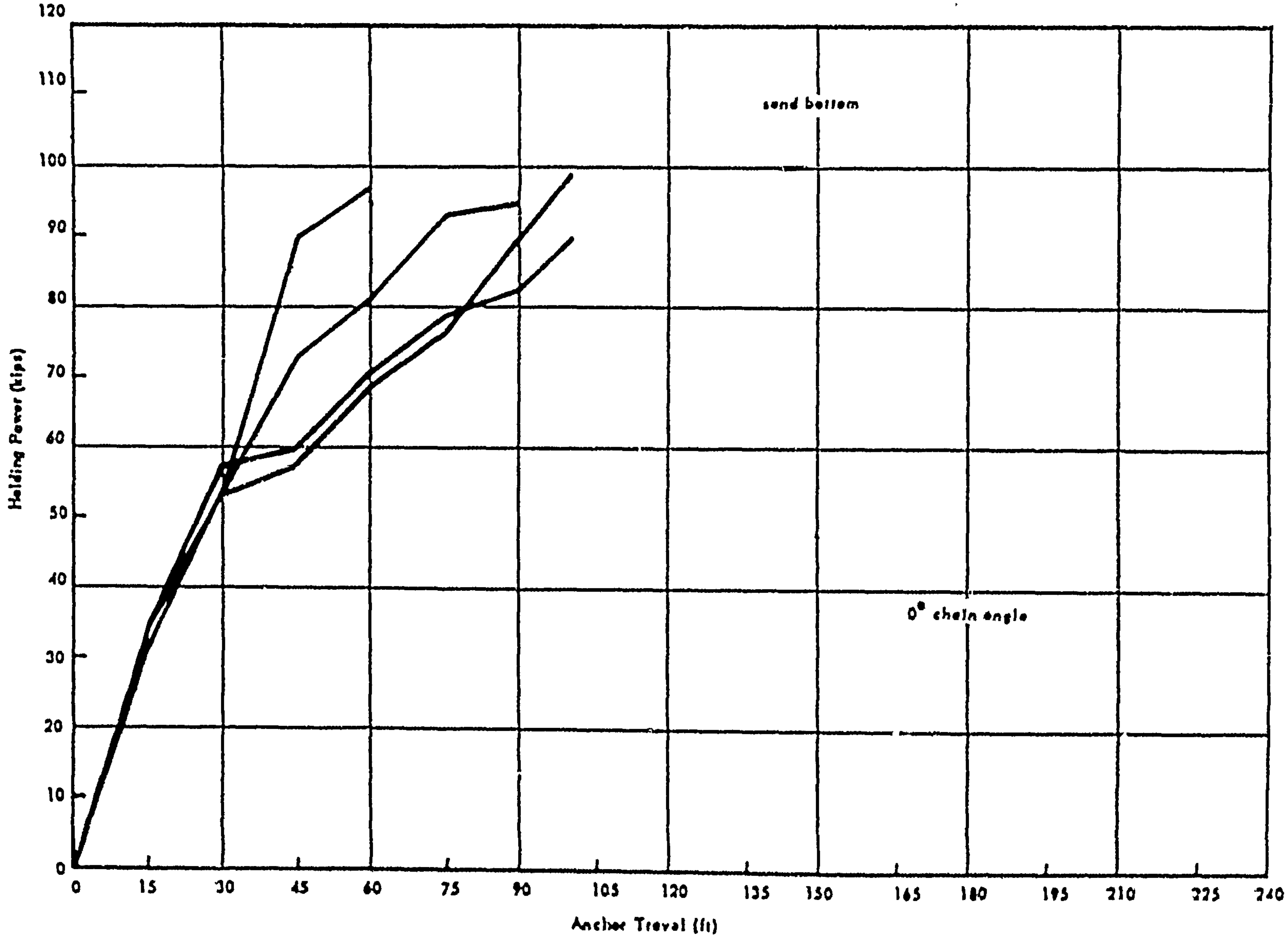


Figure E-4. Graph of test pulls on 3000-lb STATO mooring anchor.

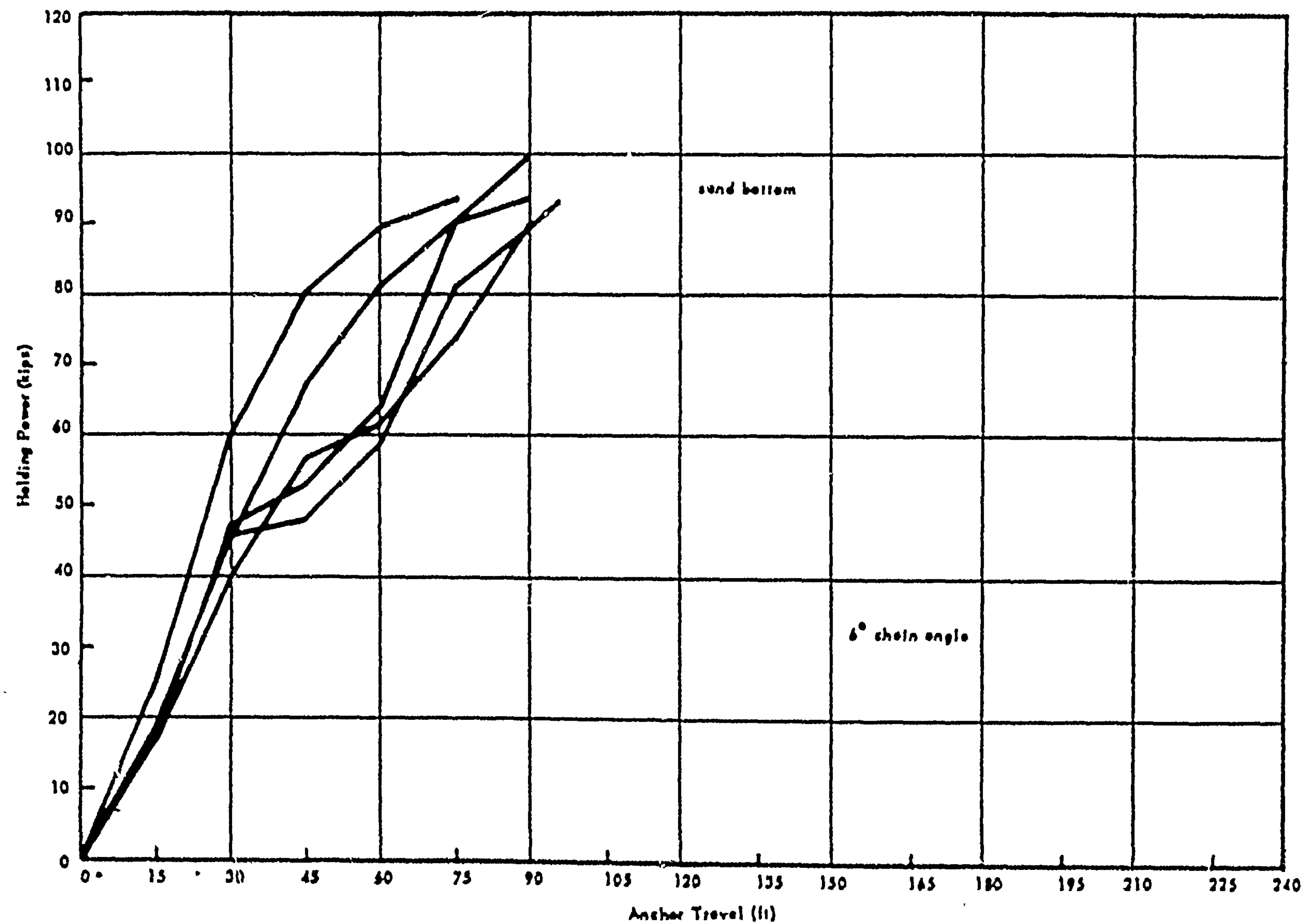


Figure E-5. Graph of test pulls on 3000-lb STATO mooring anchor.

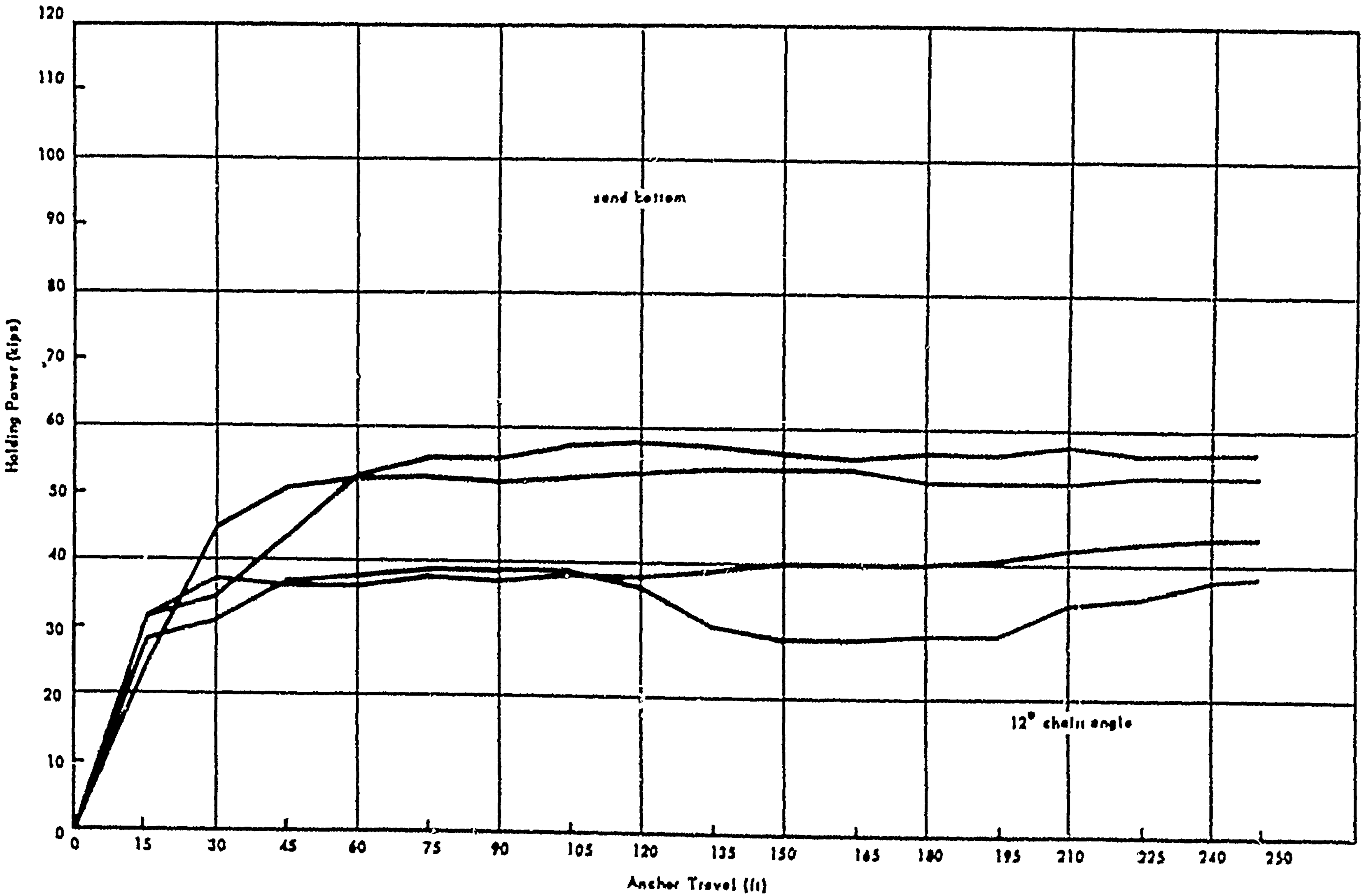


Figure E-6. Graph of test pulls on 3000-lb STATO mooring anchor.

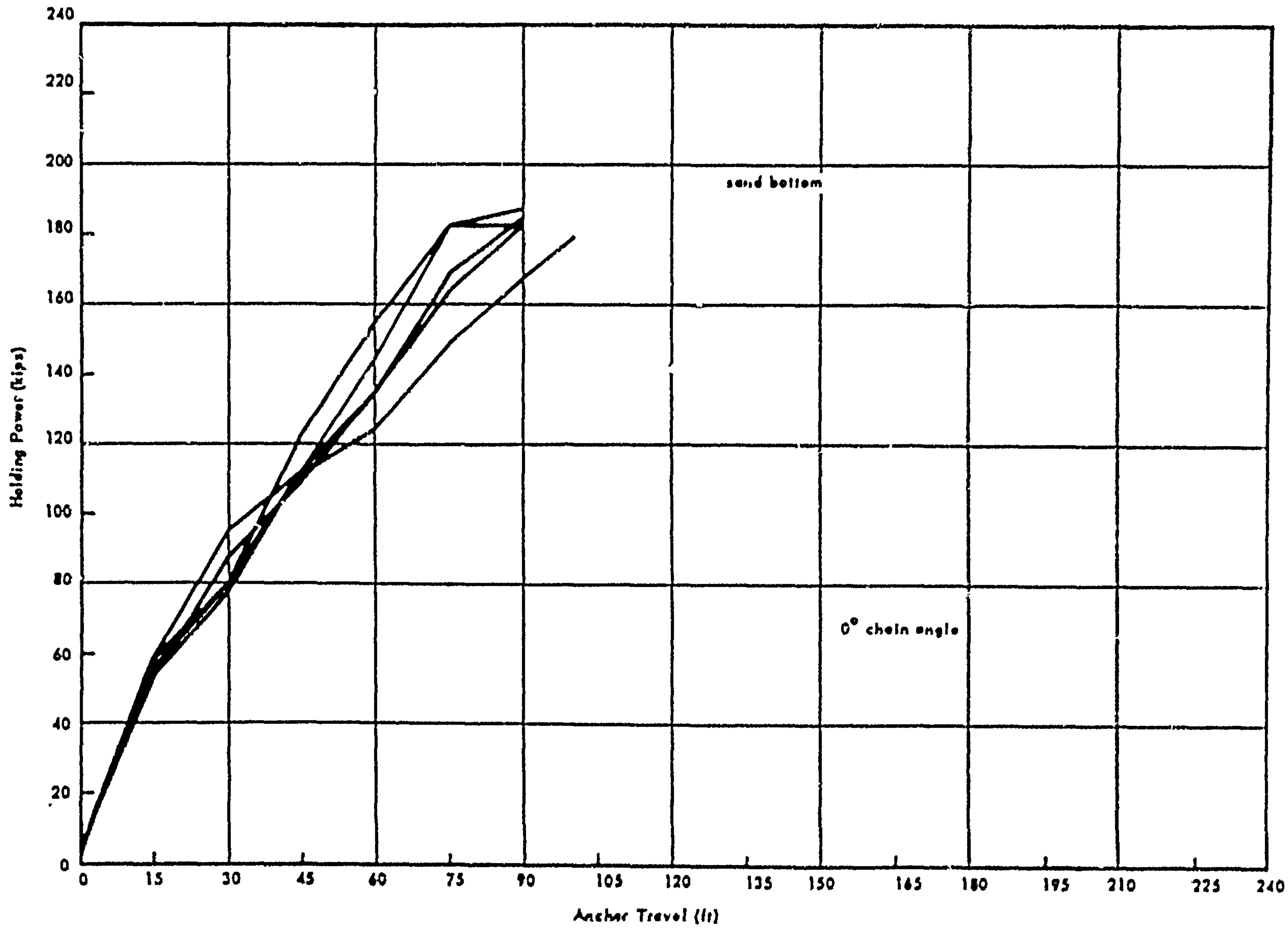


Figure E-7. Graph of test pulls on 6000-lb STATO mooring anchor.

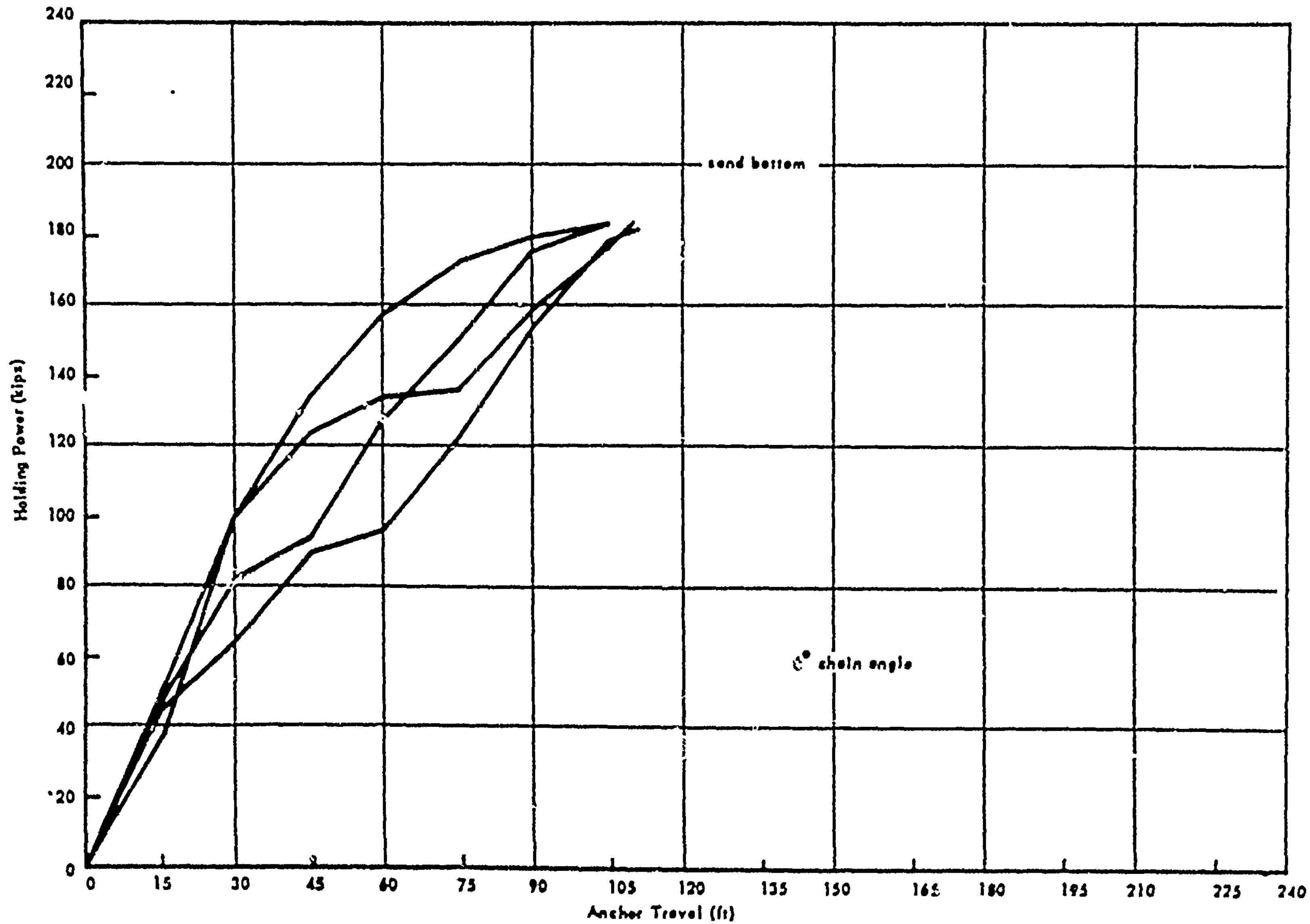


Figure E-8. Graph of test pulls on 6000-lb STATO mooring anchor.

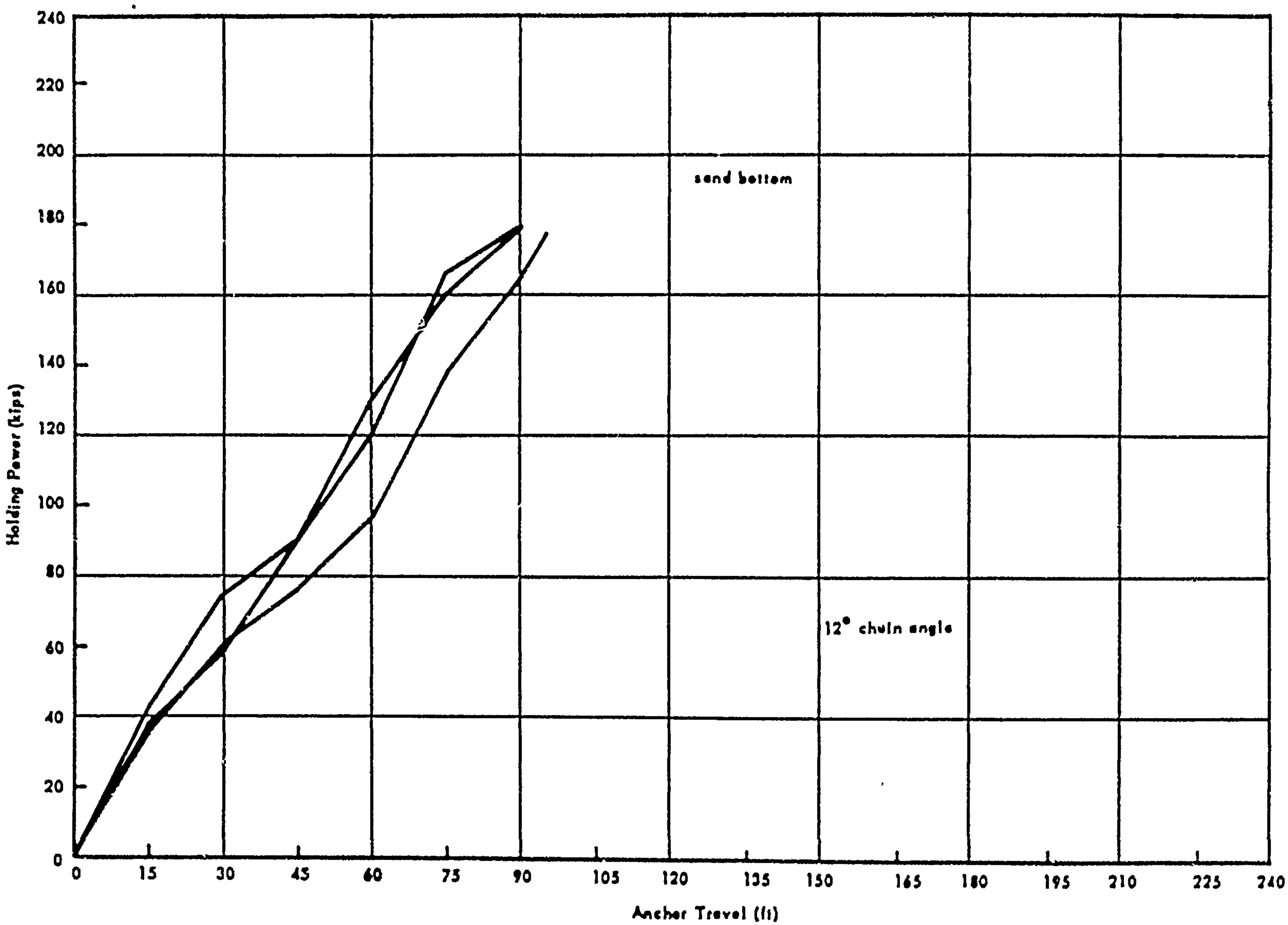


Figure E-9. Graph of test pulls on 6000-lb STATO mooring anchor.

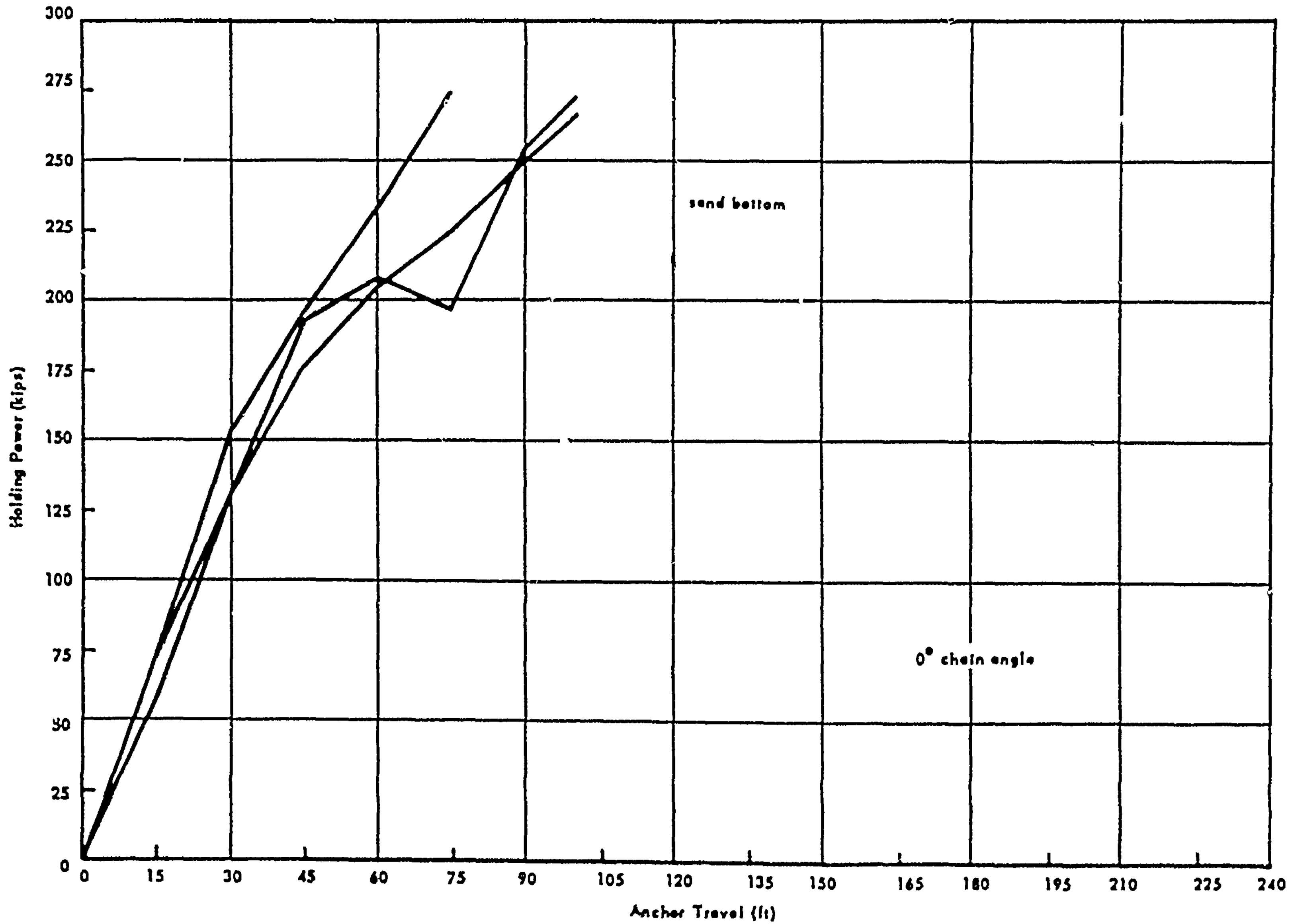


Figure E-10. Graph of test pulls on 9000-lb STATO mooring anchor.

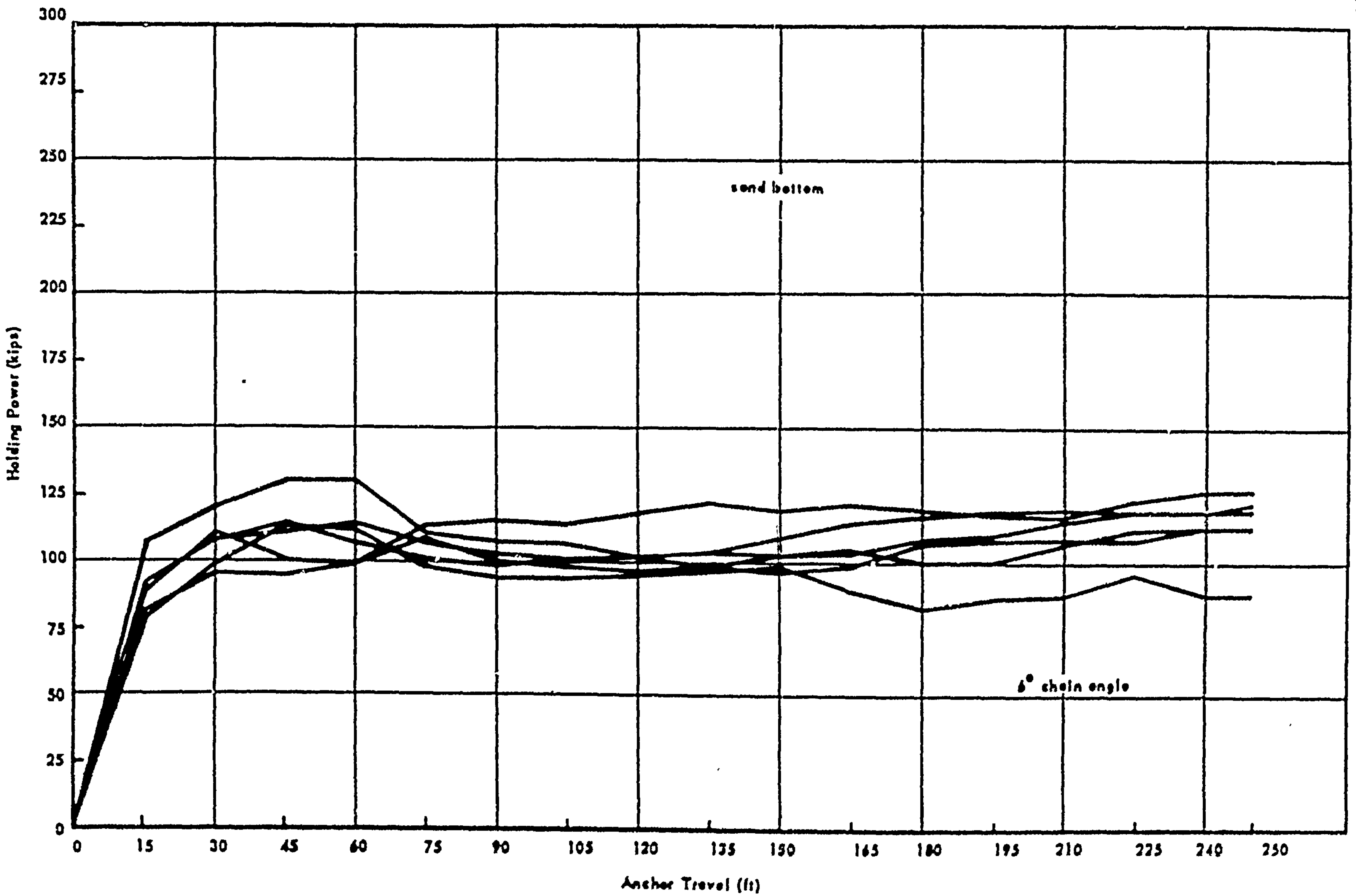


Figure E-11. Graph of test pulls on 9000-lb STATO mooring anchor.

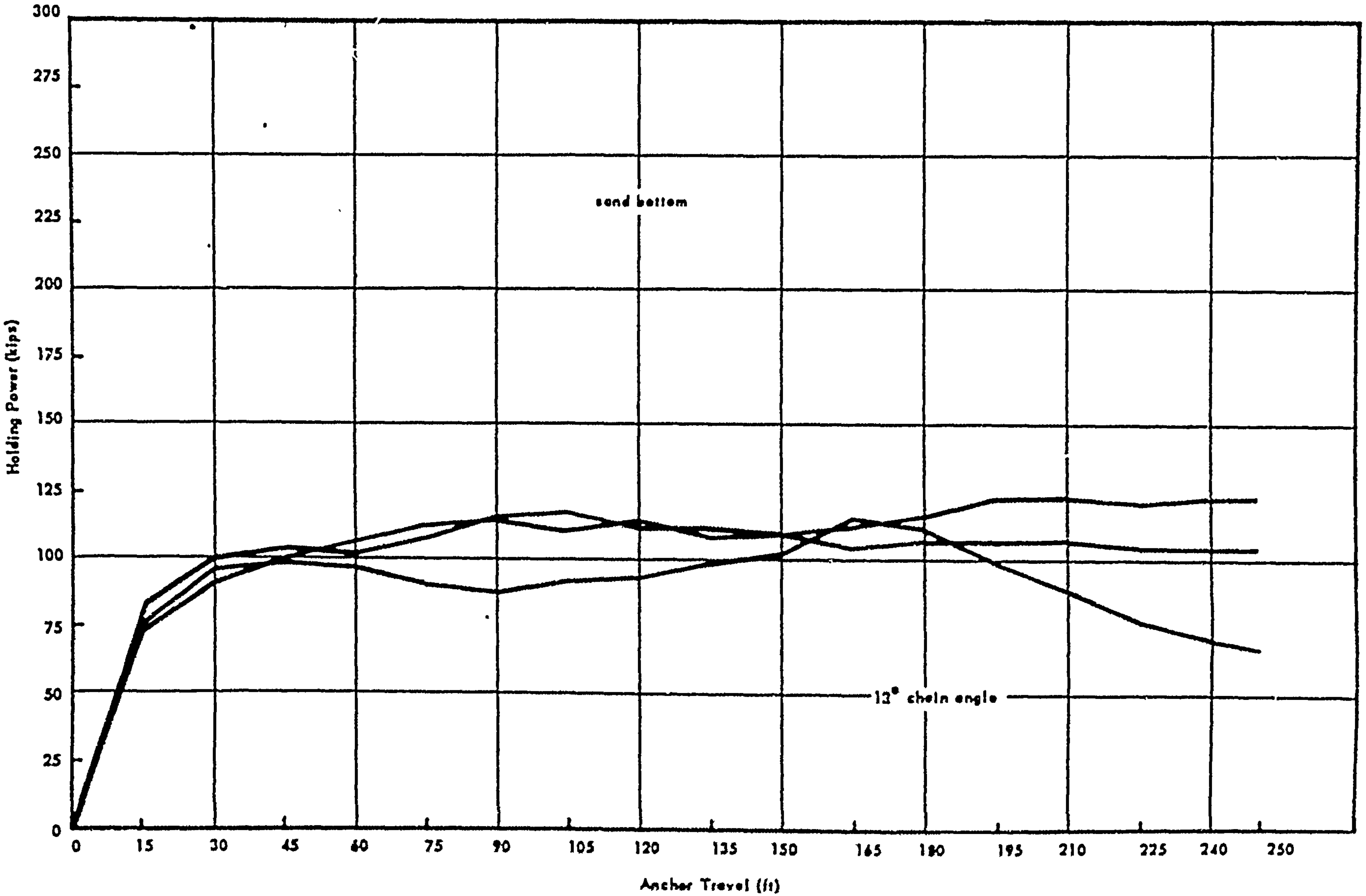


Figure E-12. Graph of test pulls on 9000-lb STATO mooring anchor.

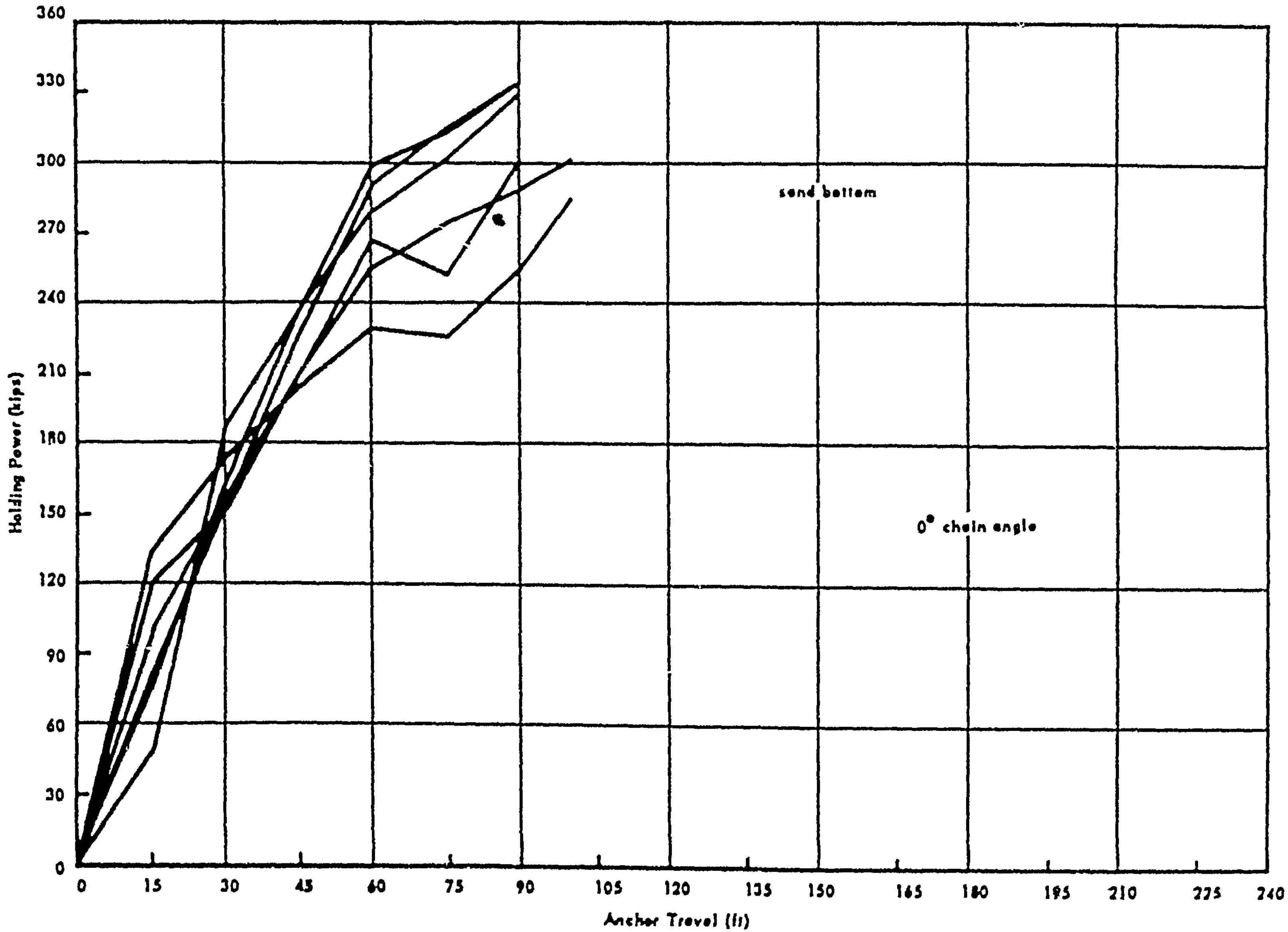


Figure E-13. Graph of test pulls on 12000-lb STATO mooring anchor.

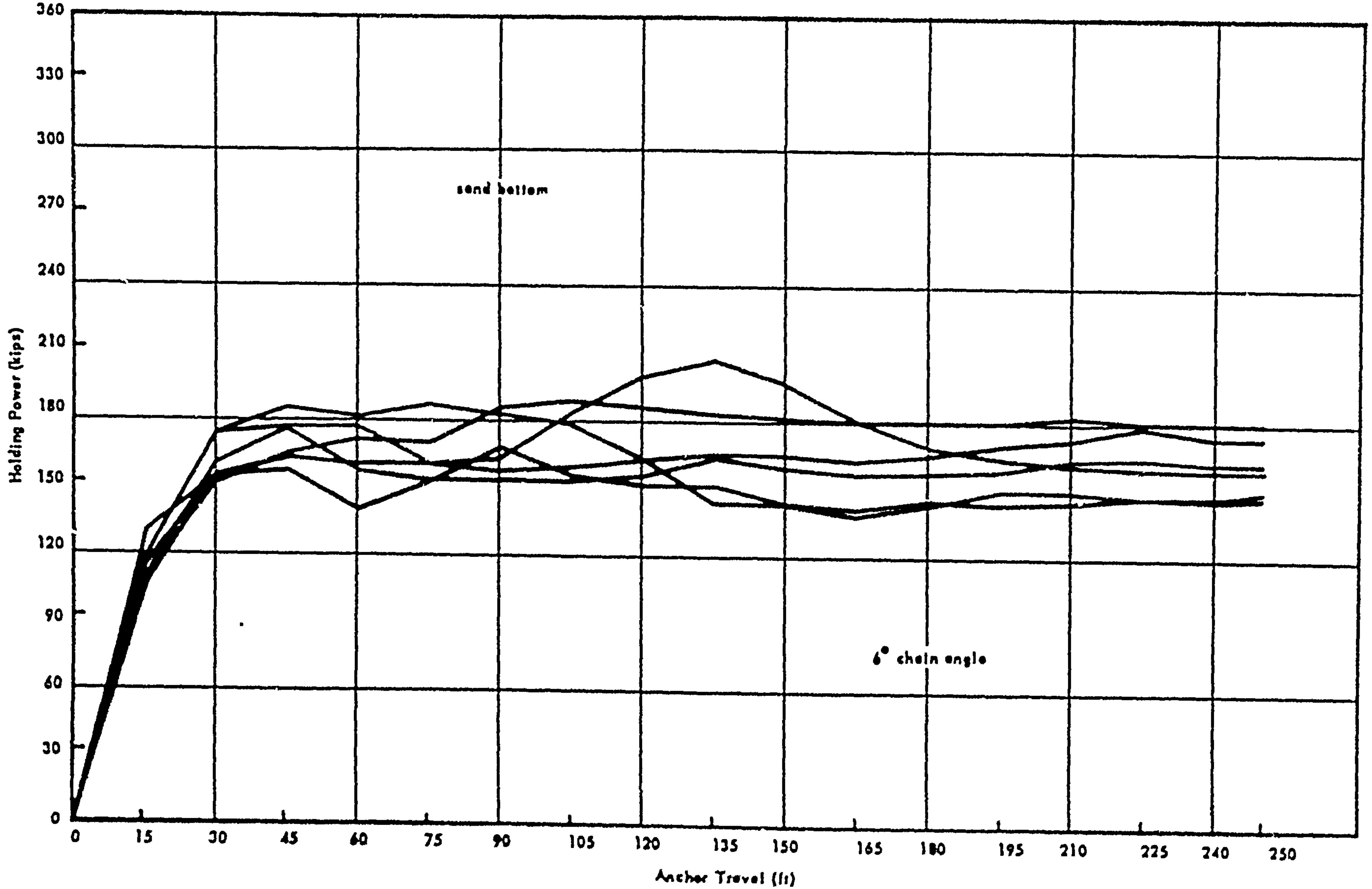


Figure E-14. Graph of test pulls on 12000-lb STATO mooring anchor.

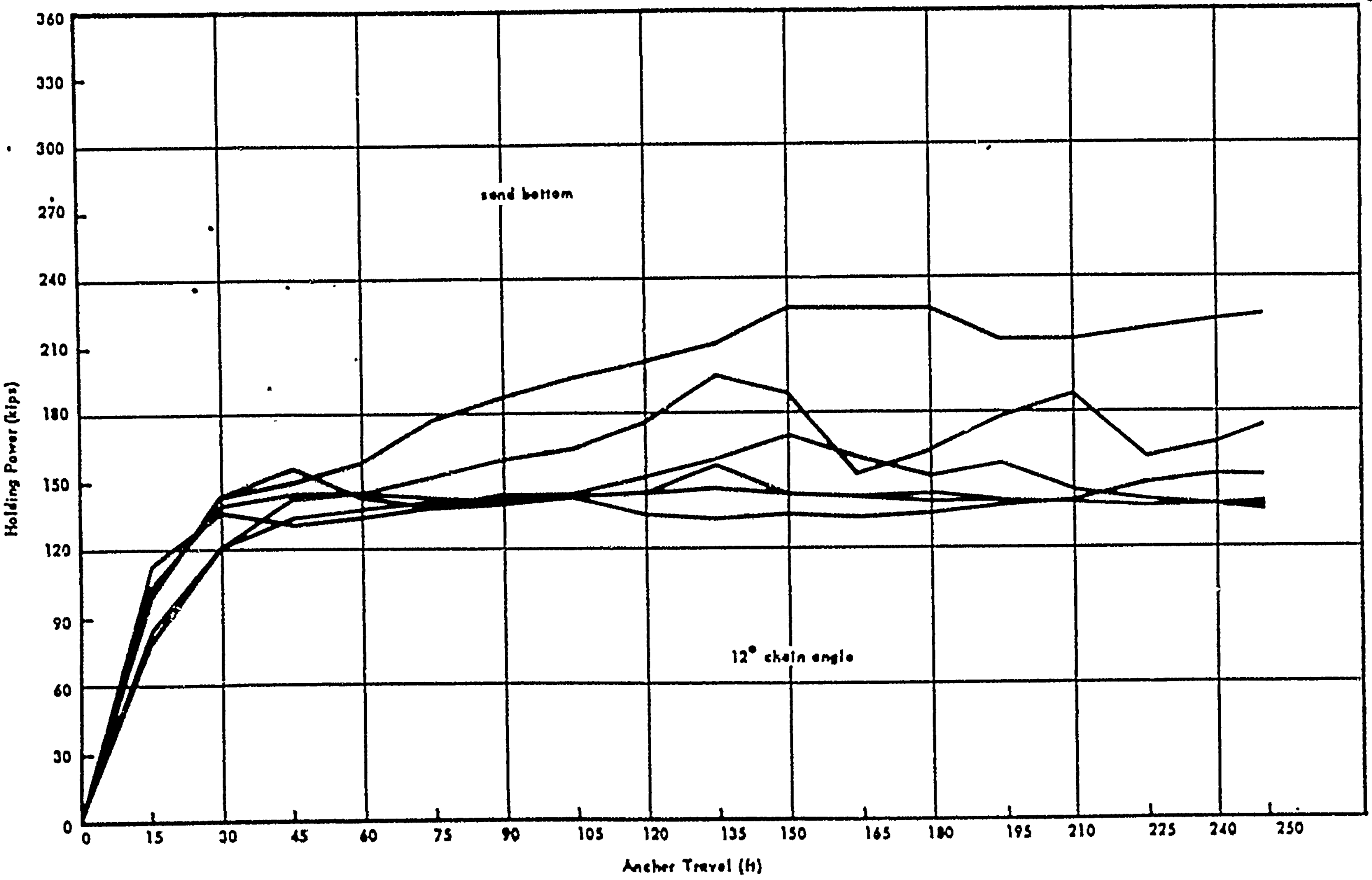


Figure E-15. Graph of test pulls on 12000-lb STATO mooring anchor.

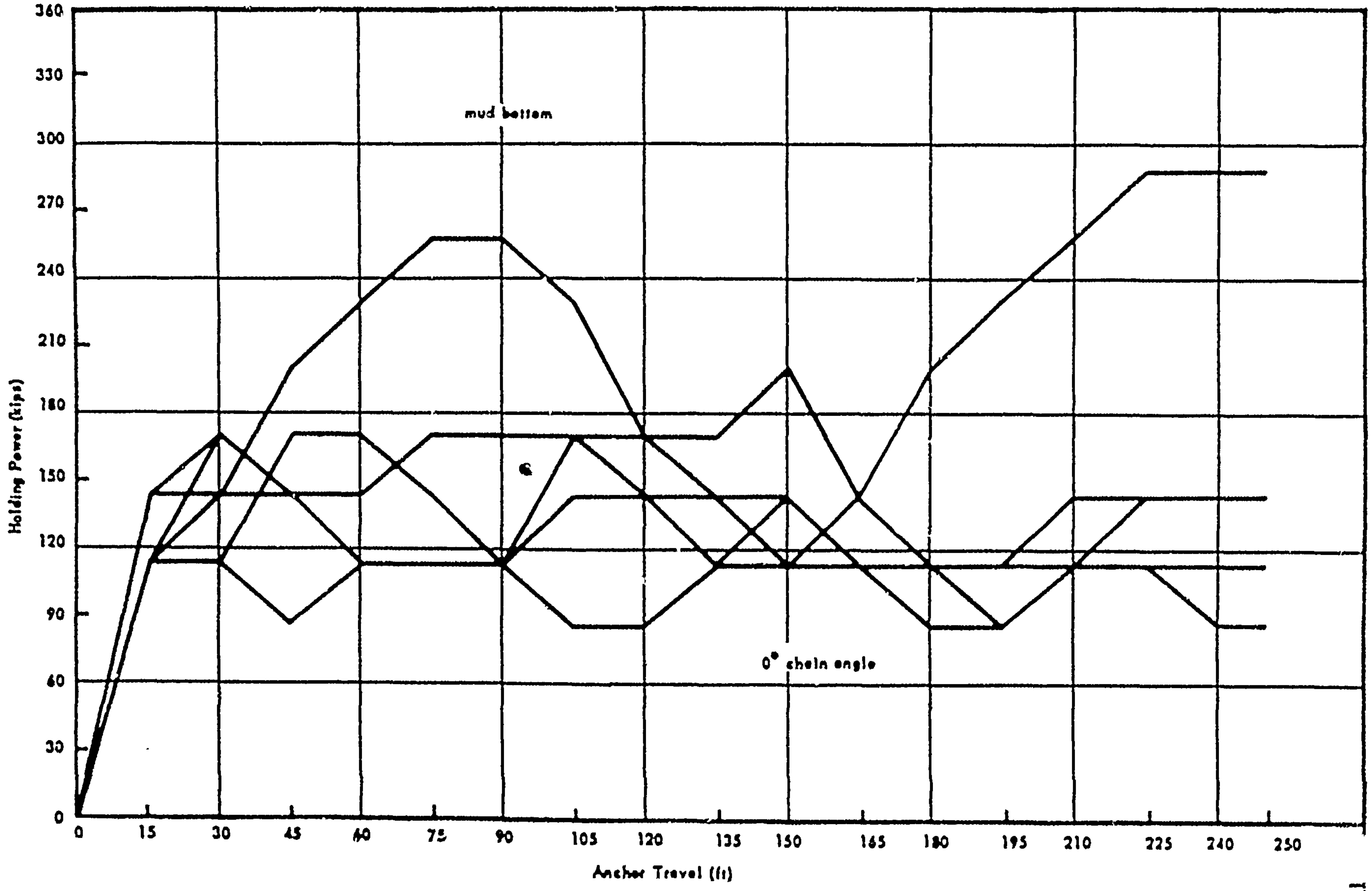


Figure E-16. Graph of test pulls on 200-lb STATO mooring anchor.

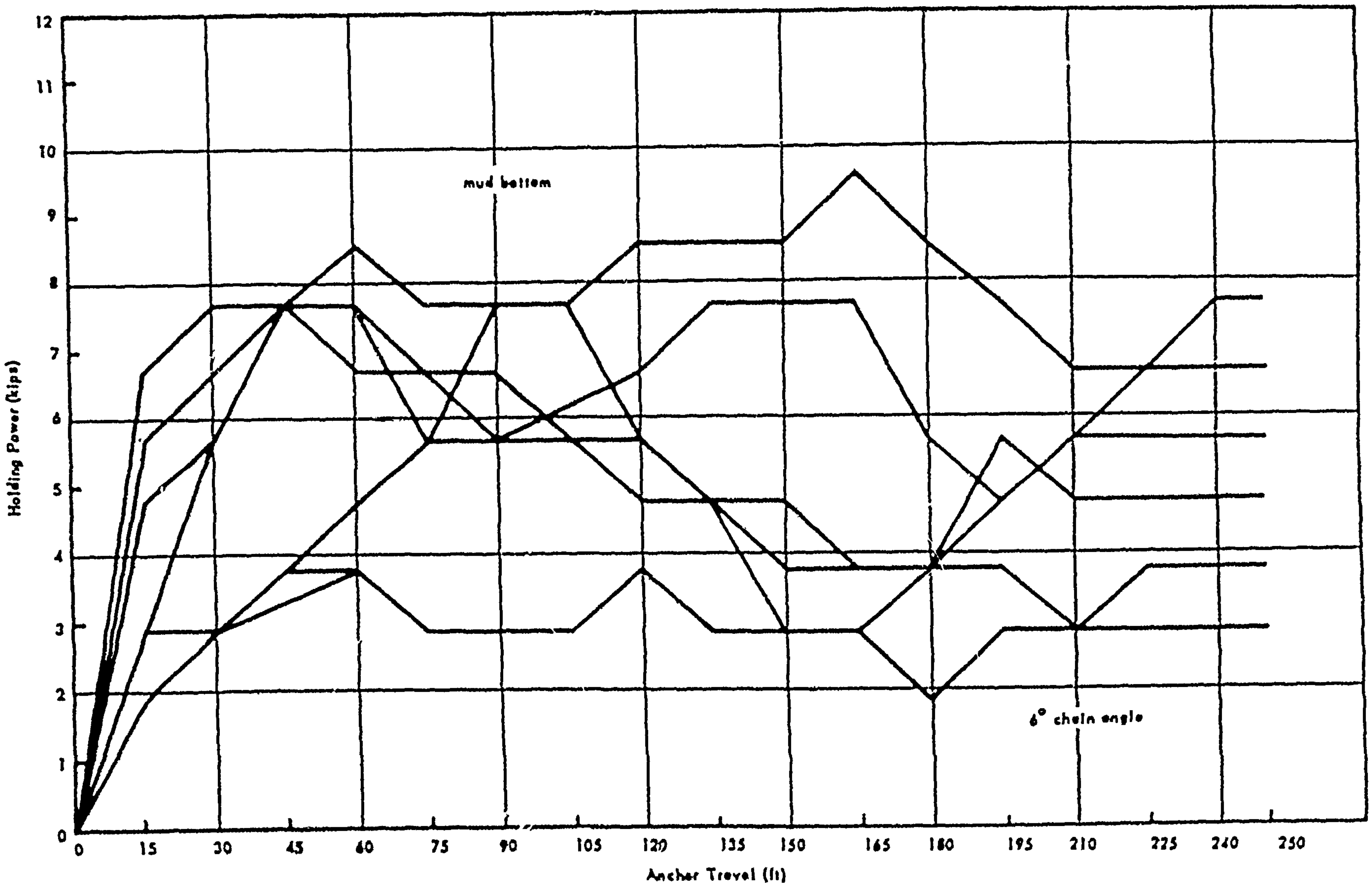


Figure E-17. Graph of test pulls on 200-lb STATO mooring anchor.

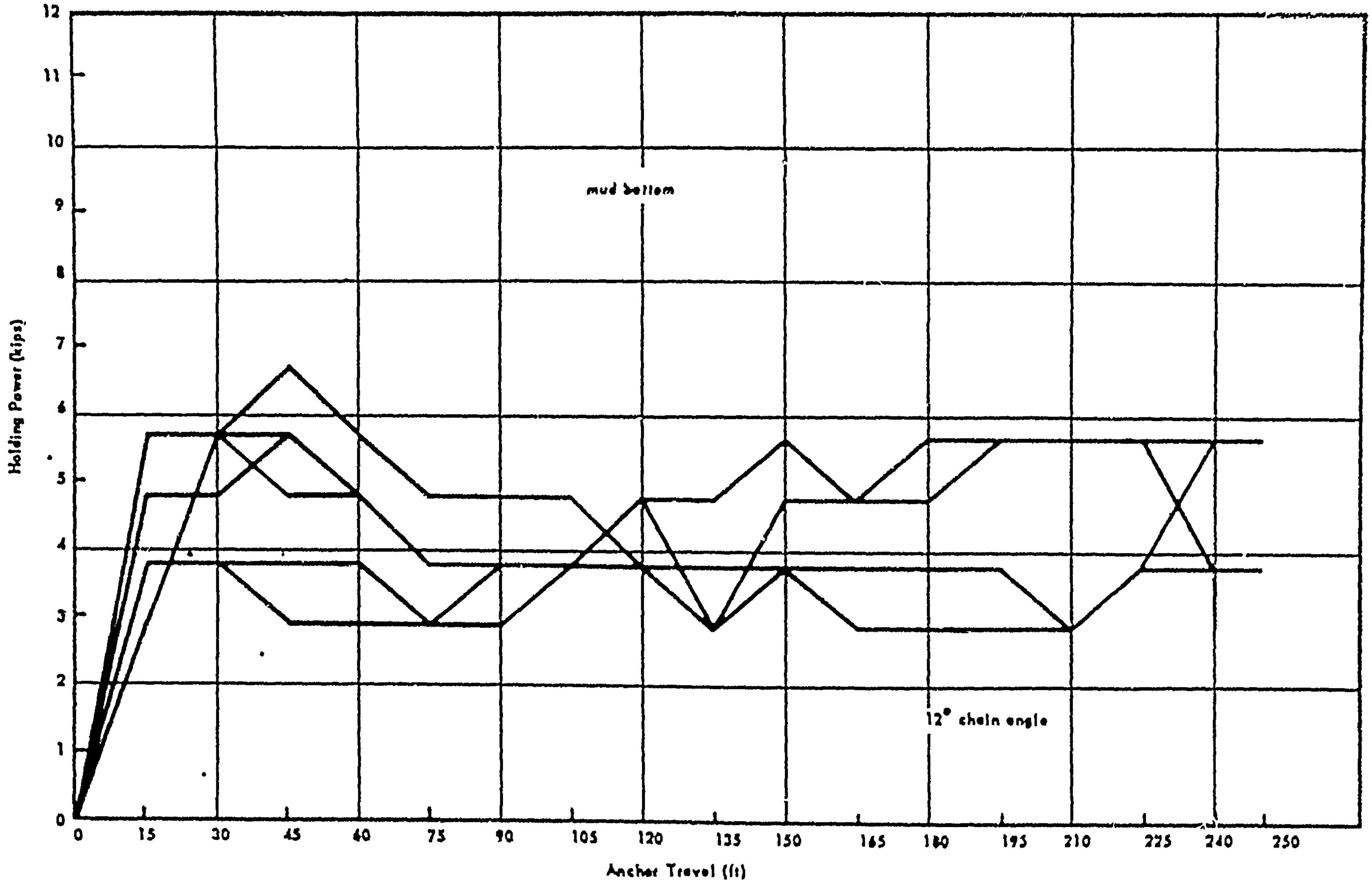


Figure E-18. Graph of test pulls on 200-lb STATO mooring anchor.

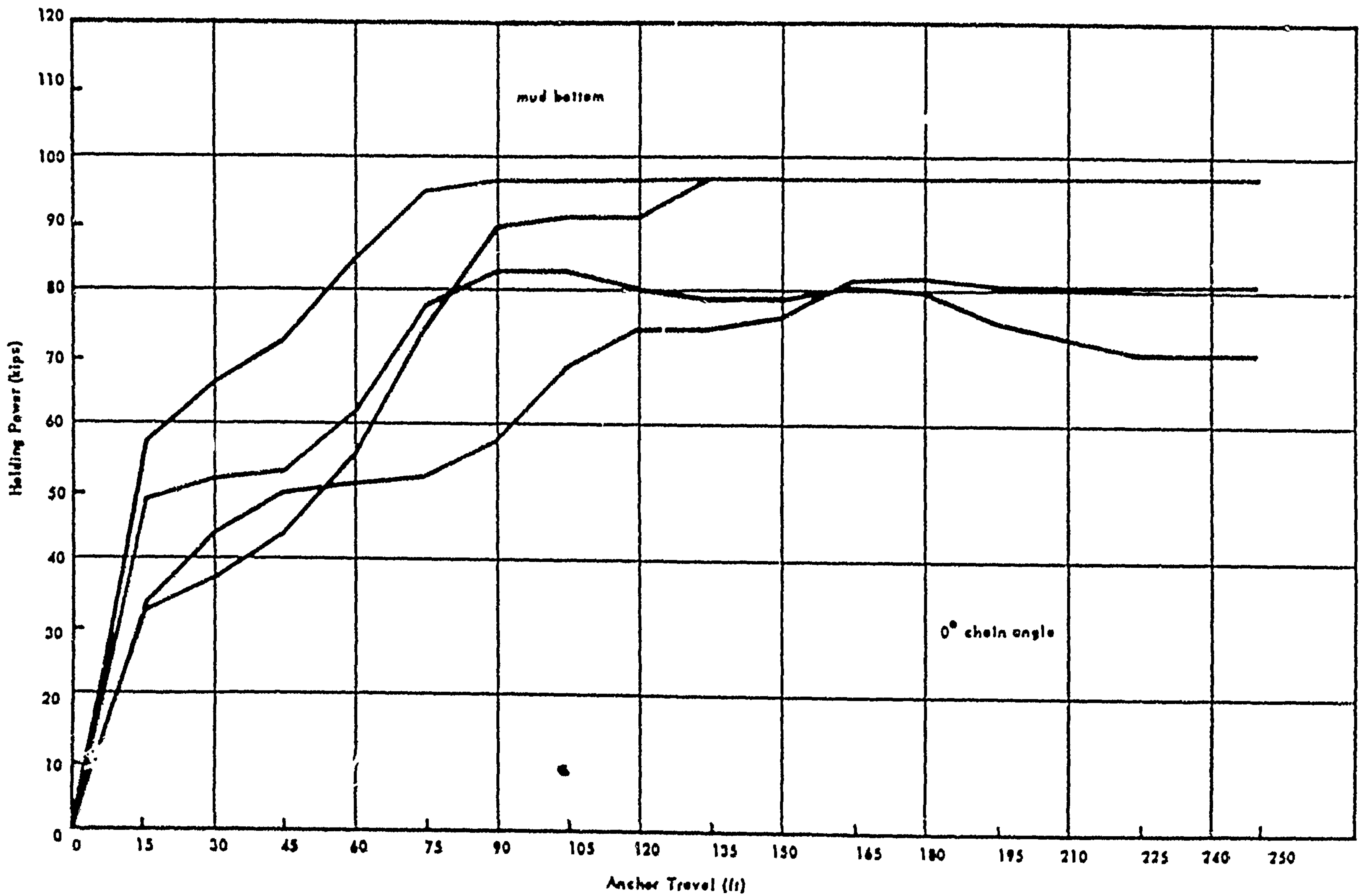


Figure E-19. Graph of test pulls on 3000-lb STATO mooring anchor.

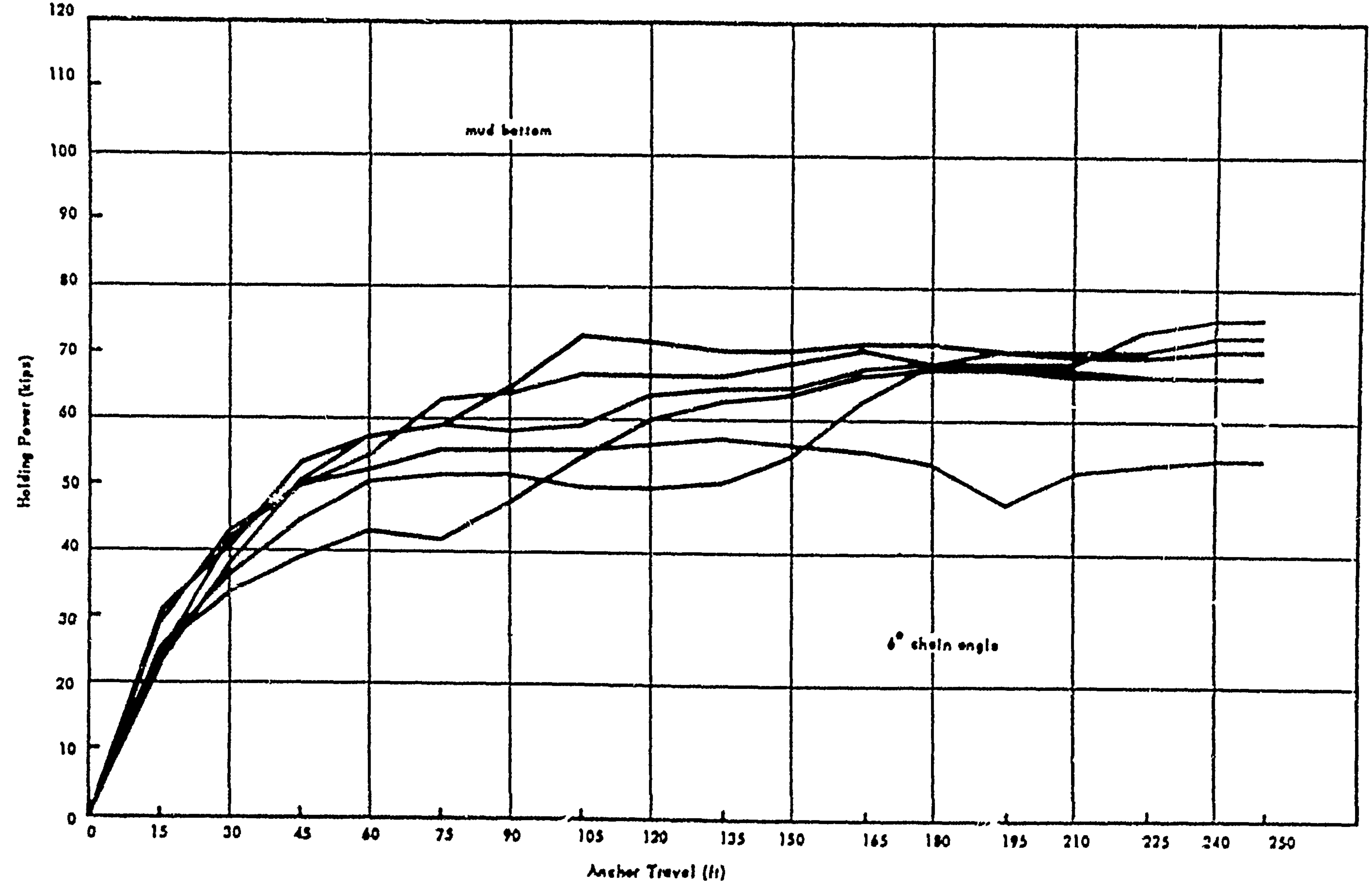


Figure E-20. Graph of test pulls on 3000-lb STATO mooring anchor.

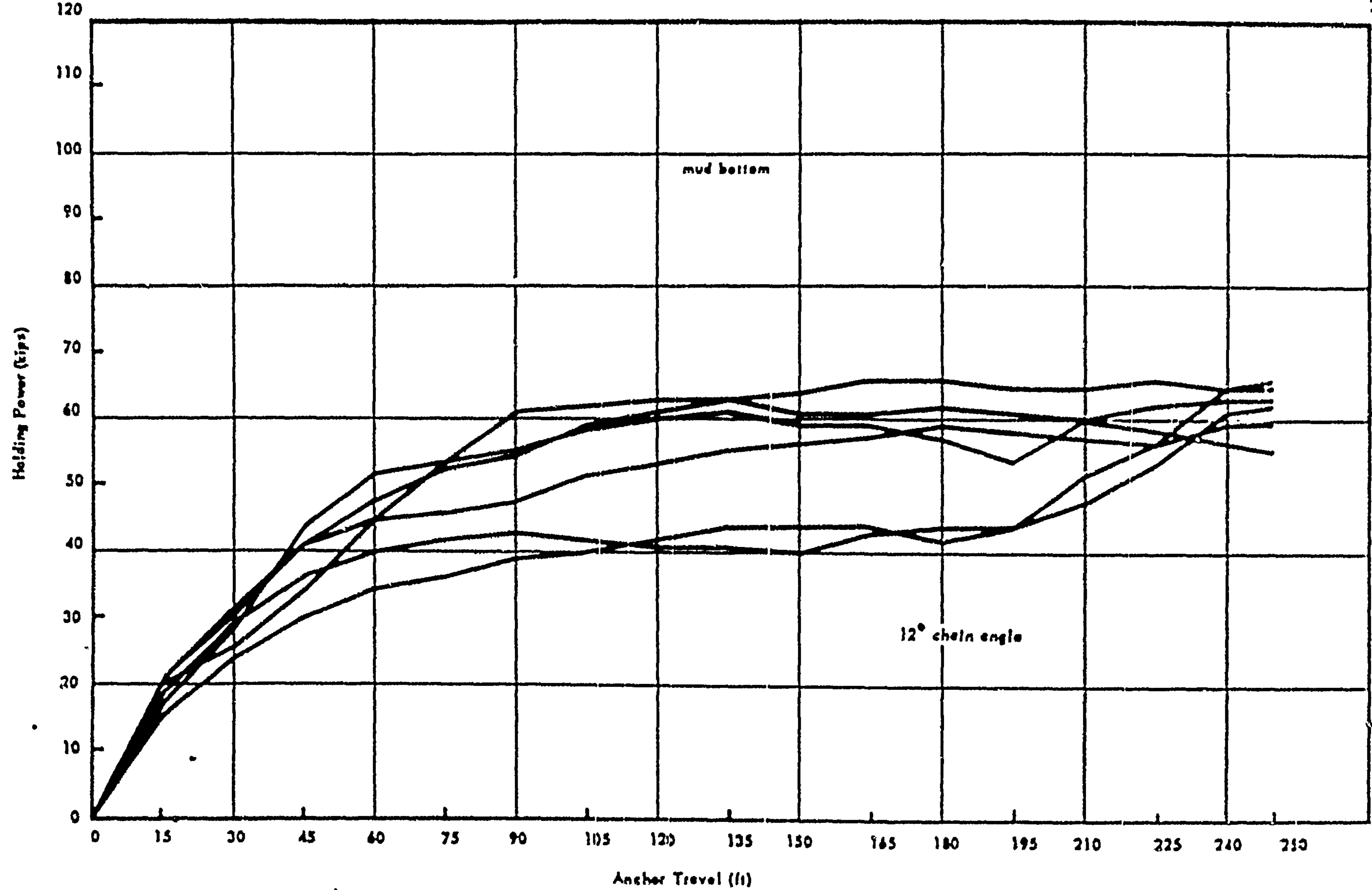


Figure E-21. Graph of test pulls on 3000-lb STATO mooring anchor.

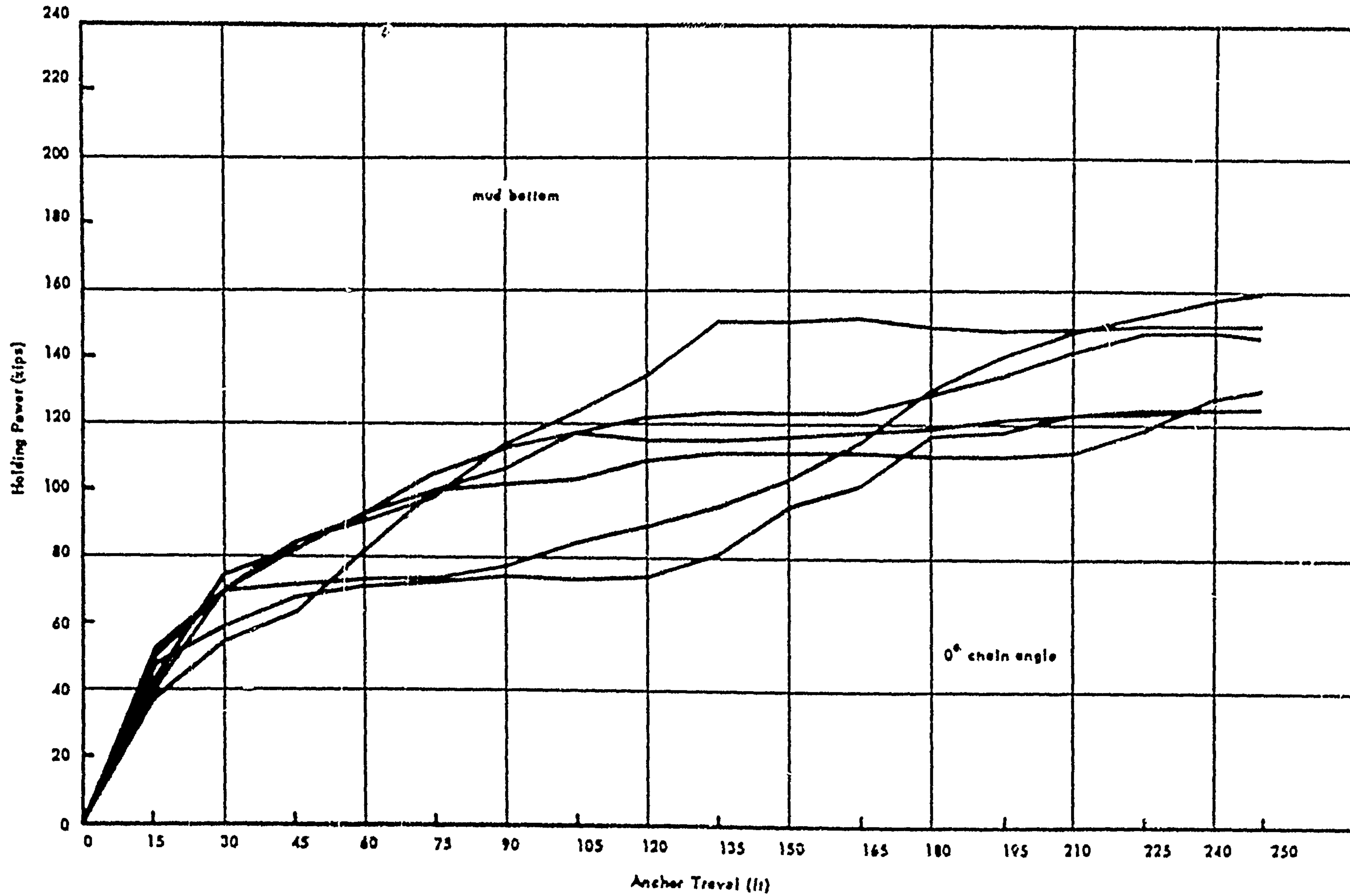


Figure E-22. Graph of test pulls on 6000-lb STATO mooring anchor.

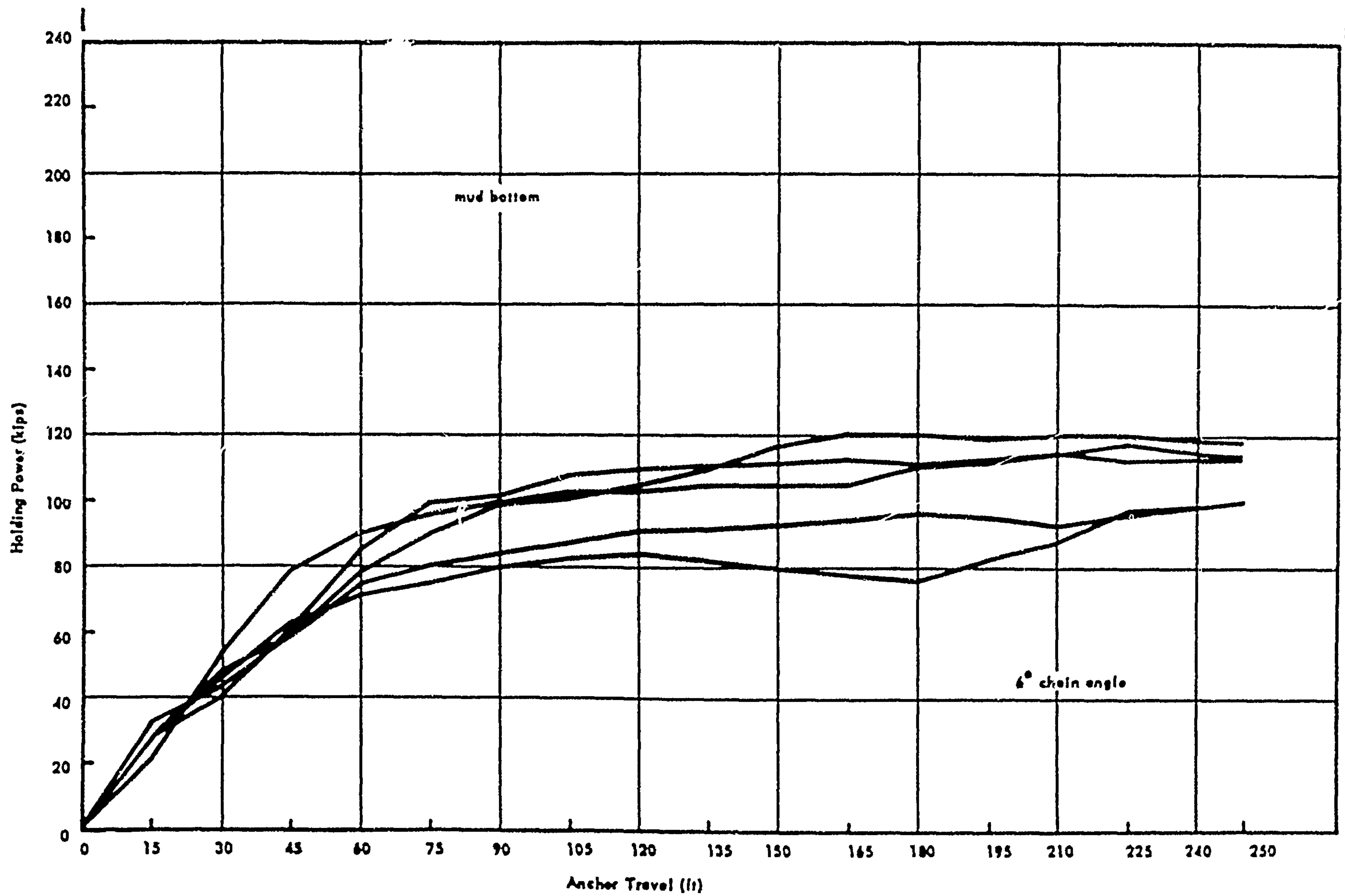


Figure E-23. Graph of test pulls on 6000-lb STATO mooring anchor.

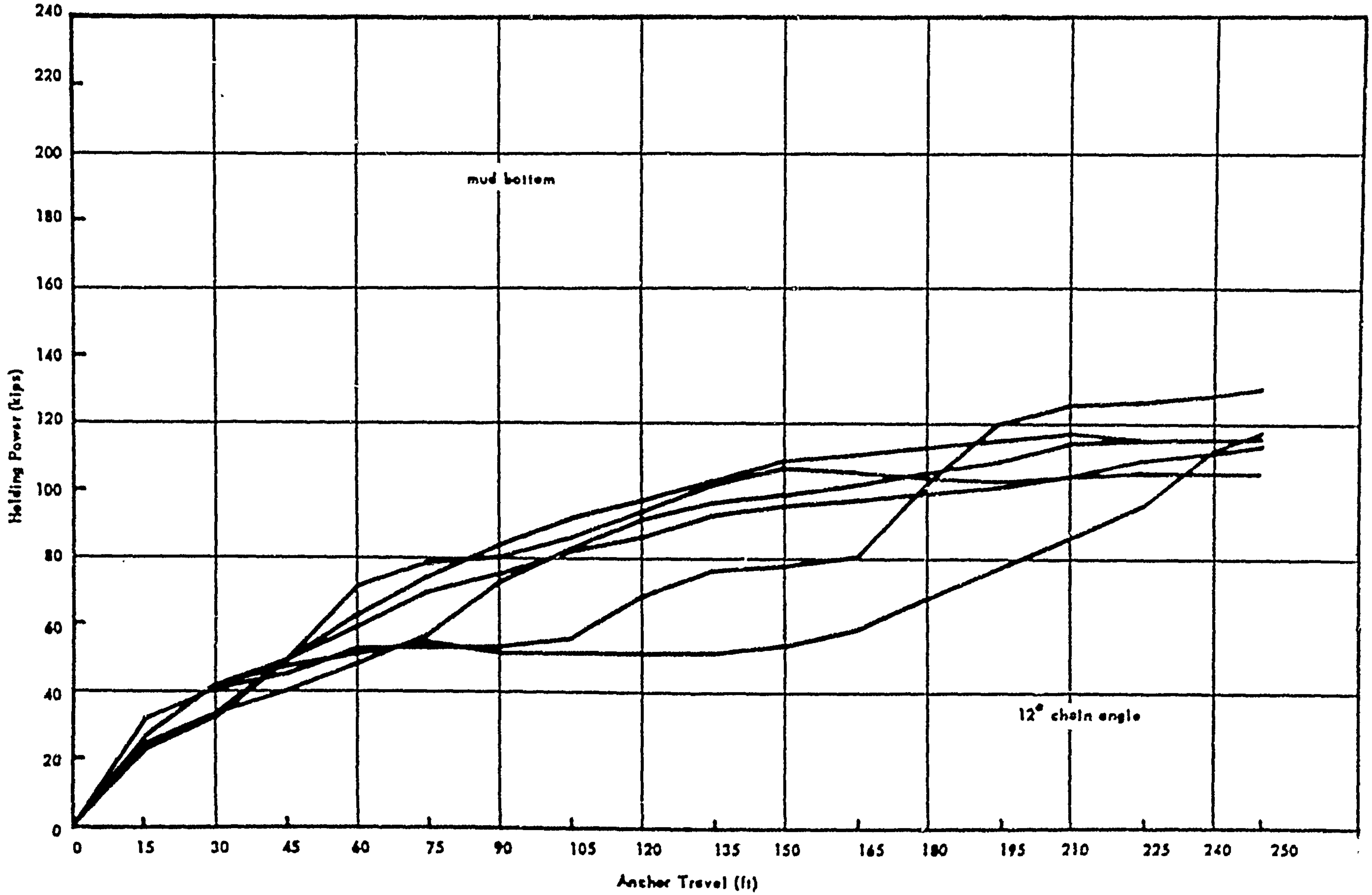


Figure E-24. Graph of test pulls on 6000-lb STATO mooring anchor.

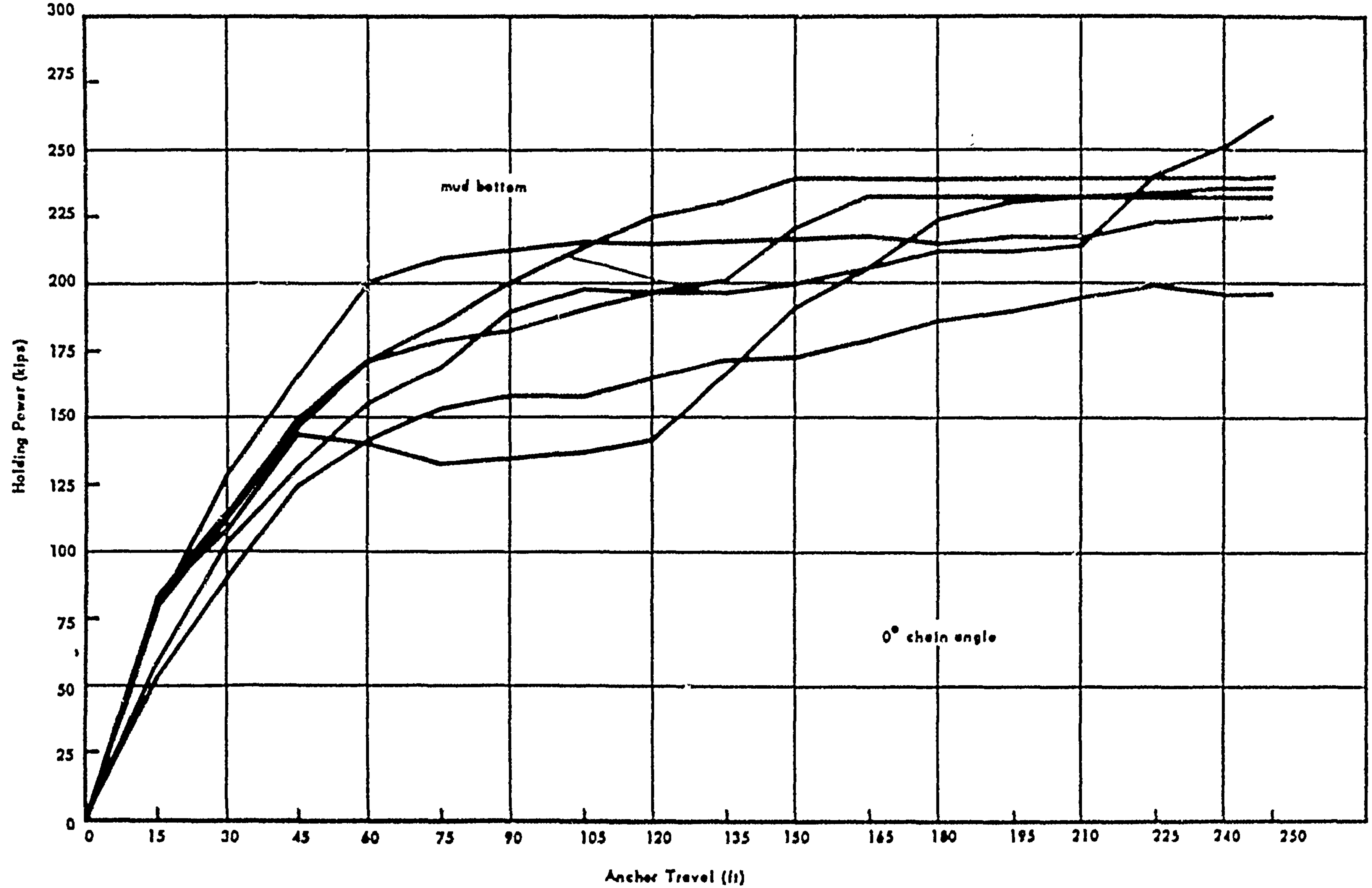


Figure E-25. Graph of test pulls on 9000-lb STATO mooring anchor.

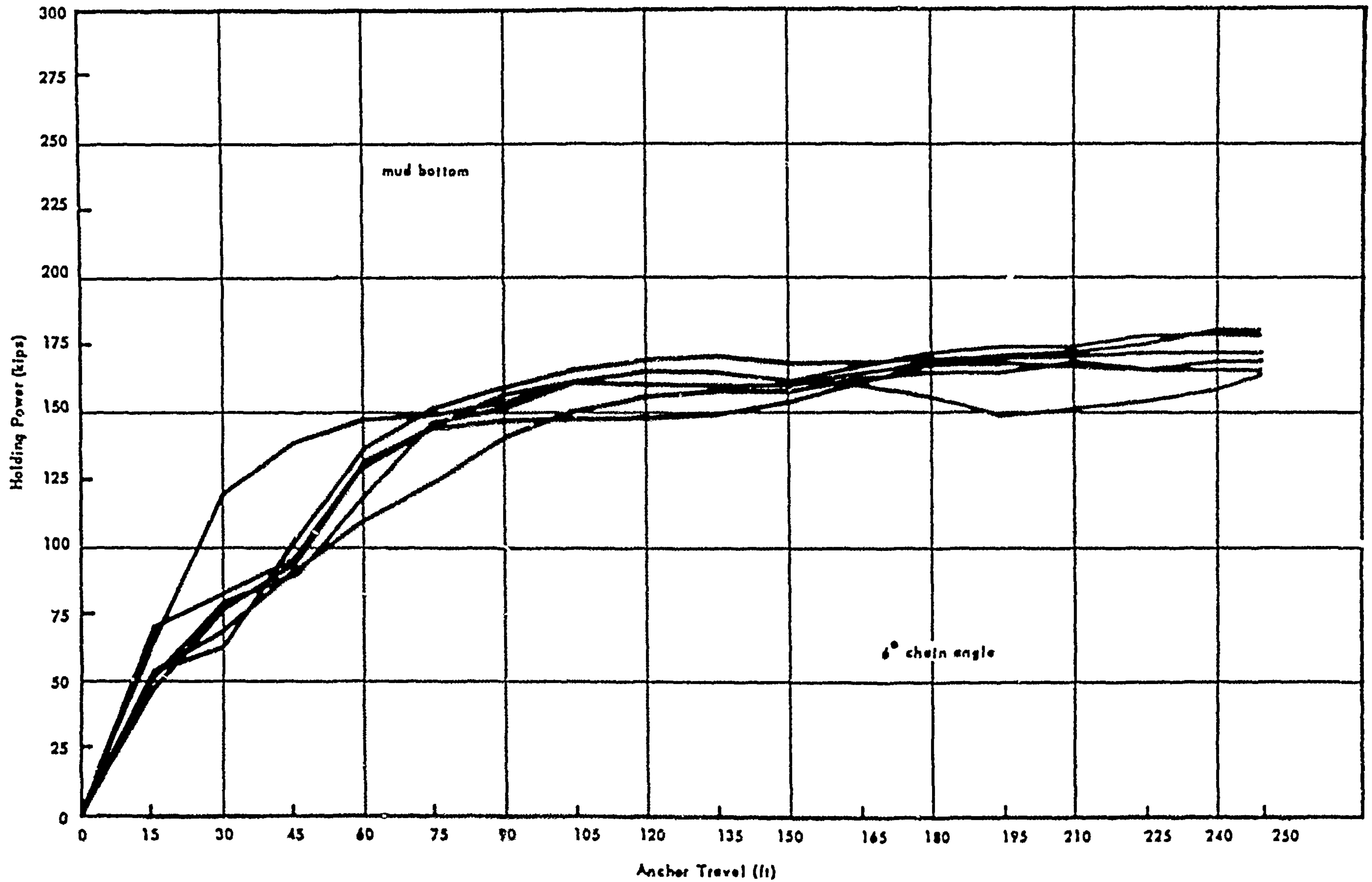


Figure E-26. Graph of test pulls on 9000-lb STATO mooring anchor.

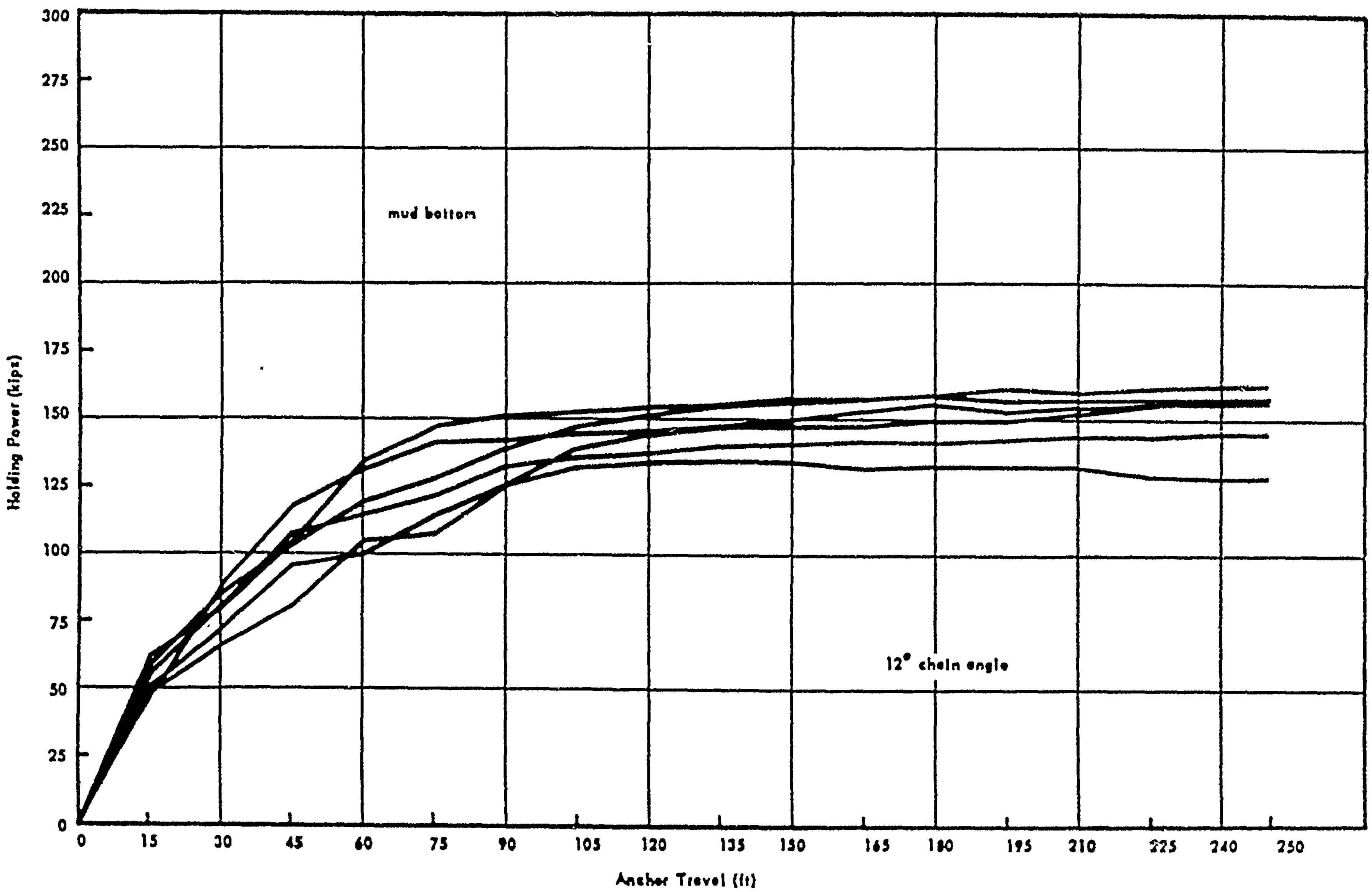


Figure E-27. Graph of test pulls on 9000-lb STATO mooring anchor.

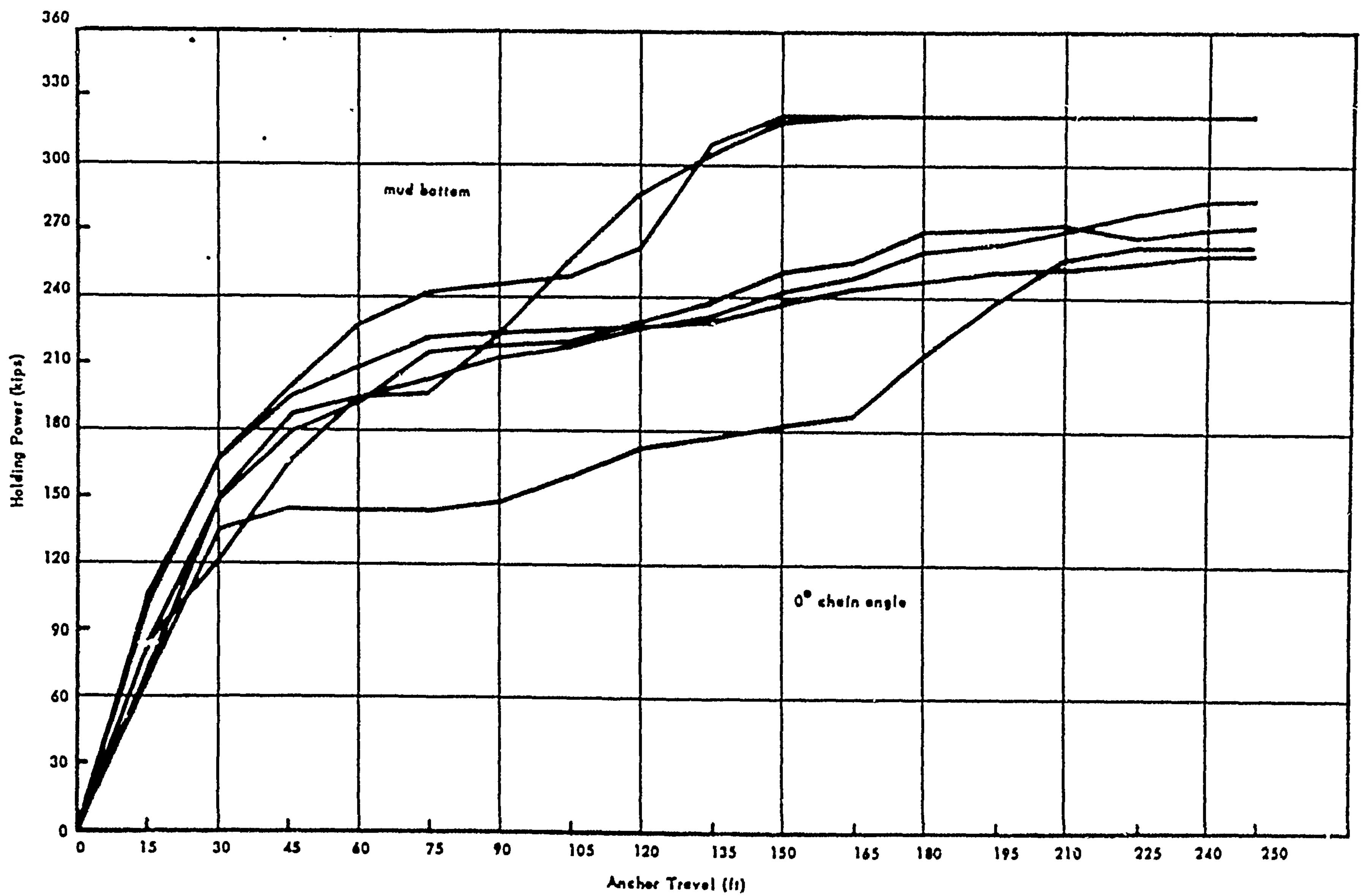


Figure E-28. Graph of test pulls on 12000-lb STATO mooring anchor.

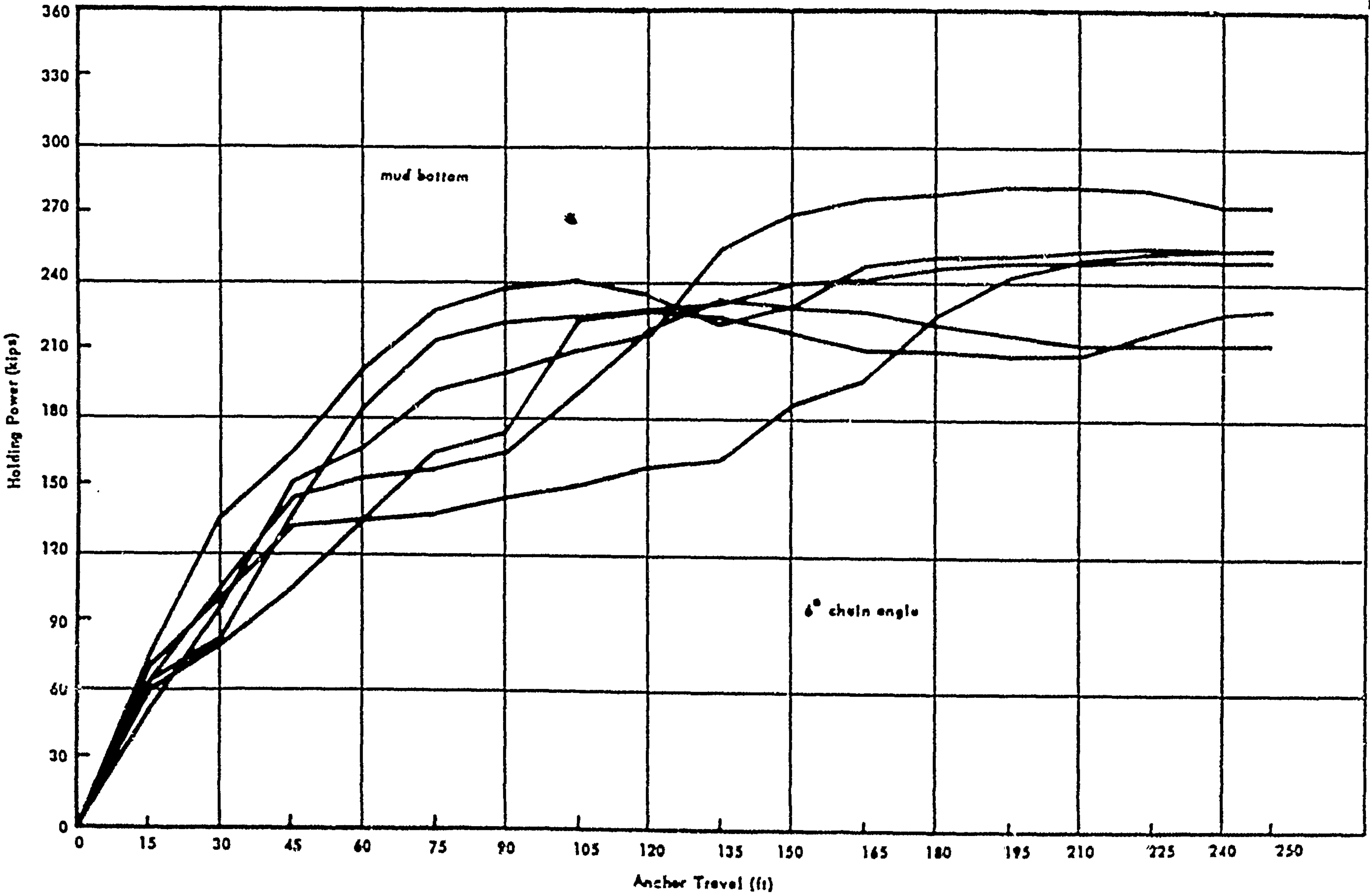


Figure E-29. Graph of test pulls on 12000-lb STATO mooring anchor.

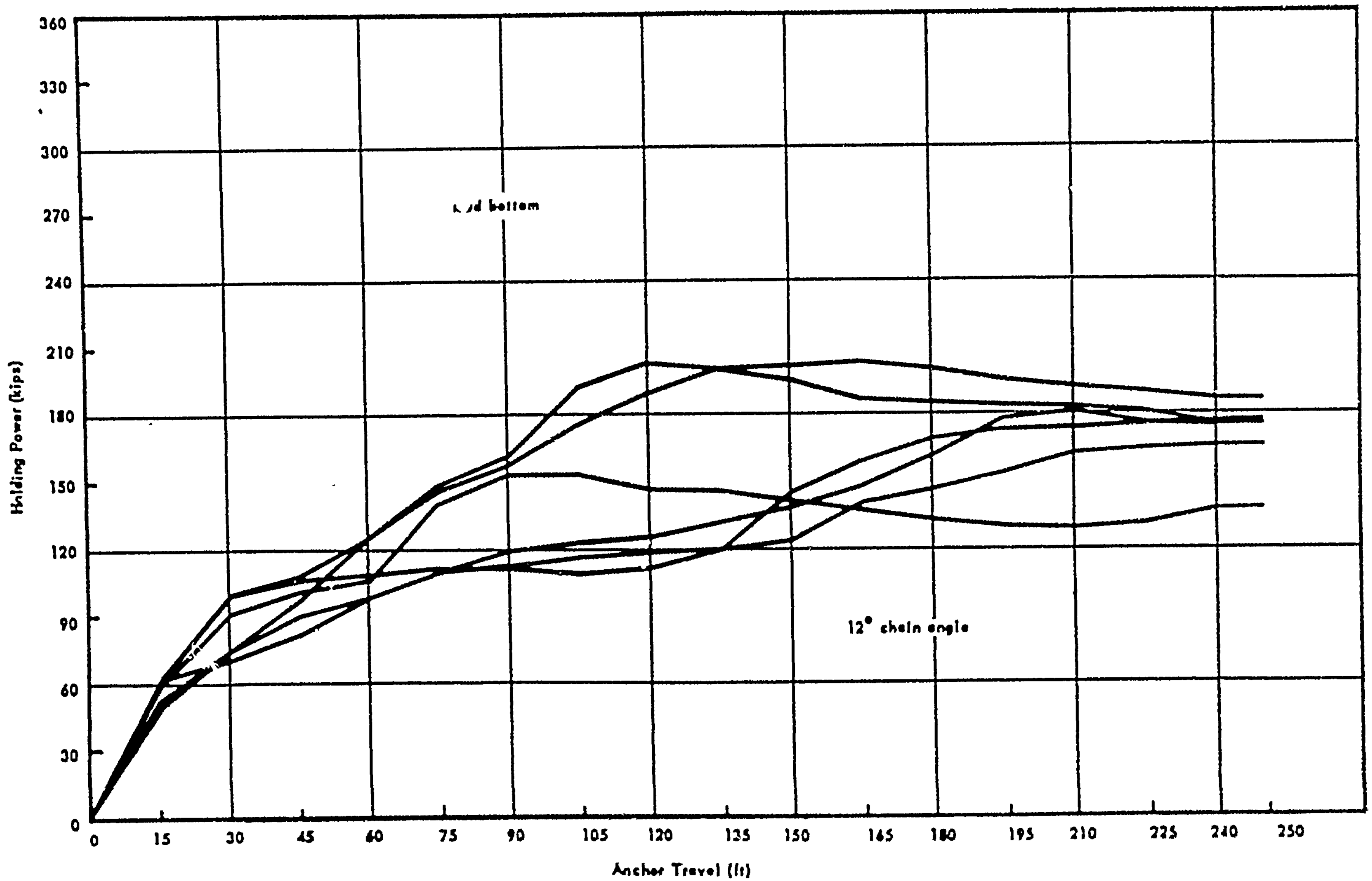


Figure E-30. Graph of test pulls on 12000-lb STATO mooring anchor.